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FREEZING IN FISHERIES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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PREPARATION OF THIS DOCUMENT

In recent years, there has been a remarkable increase in the production of frozen fish. This has been reflected in the growing number of requests for information and assistance received by the Food and Agriculture Organization of the United Nations (FAO). The preparation of this Technical Paper, as a Regular Programme activity of the FAO Fishery Industries Division, is an attempt to provide the technical background to the subjects of freezing and cold storage of fish. It is hoped that the publication will answer some of the queries raised by governments, organizations and individuals and enable them to upgrade the quality of their frozen fish.

In such a rapidly developing subject as freezing it is impossible, in a short publication, to give an exhaustive coverage, but the document is intended to serve as an introduction and background to the operations and equipment involved in freezing and cold storage of fish on shore and at sea. As far as possible, the requirements of fish freezing industries in developing countries have been covered.

Mr. J. Graham of the Torry Research Station, Aberdeen, Scotland, prepared the Technical Paper, in association with the Fish Production and Marketing Service of the FAO Fisheries Department.

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FOREWORD

Freezing has developed as a widely-used method for the preservation of fish as food. It was developments in refrigeration that promoted the large-scale expansion of the North Atlantic fishing industry and the growth of worldwide shrimp and tuna fisheries. Developing countries are increasingly introducing freezing as an efficient method of storage and distribution of fish either for local consumers or export markets.

It is therefore only natural that governments, industries, various organizations and individuals have shown great interest in obtaining technical information on freezing as well as storage and distribution of frozen fish. On many occasions the FAO Fishery Industries Division has been asked to provide information on technical aspects of freezing fish. Many of these requests have come from developing countries with the potential to introduce freezing as a means of preserving fish for direct human consumption.

The Fish Production and Marketing Service of the Fishery Industries Division of FAO's Fisheries Department has studied the trends and developments in the application of freezing techniques and has collected the information, particularly that of special interest to developing countries. This material, including the relevant parts of the recently completed "Code of Practice for Frozen Fish" has now been incorporated by Mr. J. Graham in this publication "Freezing in Fisheries". The title itself implies a close connexion with the FAO publication "Ice in Fisheries", which deals with chilling of fish, and which was in such demand that it has been reprinted several times. In addition to his own experiences, and the information from the Torry Research Station, Aberdeen, Mr. Graham has drawn freely on available literature and on information provided by manufacturers of refrigeration equipment. As it is not practicable to list all the contributors, a general acknowledgement is made.

Steps will be taken to keep the content of this review on freezing in fisheries up to date, and to supplement it by the addition of more information, particularly relating to tropical and sub-tropical developing countries, as such information becomes gradually more available. Any comments and additional information on the application of freezing and cold storage in fisheries throughout the world will be highly appreciated.

A. Labon
Director
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1. FREEZING OF FISH

The purpose of freezing fish

The purpose of freezing fish is to lower its temperature and thus slow down spoilage so that when the product is thawed after cold storage it is almost undistinguishable from fresh fish.

The need for freezing and cold storage will arise when preservation of fish by other means, such as chilling with ice, is unsuitable for the period of storage time involved. Preservation of fish by chilling may only be suitable for a number of days, or a week or two at the most, whereas good freezing and cold storage will enable the fish to be kept for months or even up to a year or more.

Preserving fish by freezing has a number of applications. If the fishing grounds are a long way from the port of landing and fishing trips last many days, freezing at sea will have to be considered as a means of keeping the catch in good condition. If the consumer market is distant from the fishing port, freezing may again be necessary to preserve the fish during the period of storage, transportation and distribution.

Freezing may also be considered when there are periods of glut and scarcity. Freezing at times of plenty and storage at low temperature, allows fish to be marketed in accordance with demand. This is to the advantage of the fisherman, the processor and the consumer since it results in the regulation of supplies, more uniform and usually better fish quality and more stable prices.

The long periods of storage that good freezing and cold storage practice allow, also means that fish that are caught only during short fishing seasons may be made available all the year round.

Many fish processes involve a high investment and require a good deal of labour. Freezing the fish and processing at a regular rate, rather than in accordance with an unpredictable supply will mean better utilization of these resources.

Preservation by freezing and cold storage is usually required if fish are to be exported. Export of frozen fish is often important to a developing country since expensive fish products, such as frozen shrimp, are more valuable as foreign currency earners than as a food for home consumption.

The many advantages of freezing are therefore obvious and, in developing countries, the requirements for freezing are only now arising due to the expansion of fisheries. Freezing and cold storage will allow this valuable protein food to be distributed to a wider market.

How fish go bad

A fish goes bad principally from two causes, through self-digestion and as a result of the action of bacteria. Breakdown of the flesh by self-digestion is encouraged by the presence in the living fish of substances known as enzymes which remain active after the fish dies. Enzyme activity in the dead fish can be reduced by lowering the temperature.

Bacteria are present in the guts and on the skin and gills of the living fish and, while the fish is alive, most of them do no harm, and may even be beneficial. But when the fish dies, they begin to increase in number and invade the flesh, which they use as food. They break down the complex chemical substances of the flesh and produce increasing amounts of simpler, objectionable compounds such as ammonia; this spoilage process continues until the flesh becomes putrid and inedible. Bacterial action is also slowed down as the temperature is reduced.

In addition to the above two methods of spoilage, fatty fish also deteriorate due to oxidation of the fat (lipid) content of the flesh, resulting in rancidity and off flavours. Again, lowering the temperature slows down this spoilage process.

Thus, by lowering the temperature of the dead fish, spoilage can be retarded and, if the temperature is kept low enough spoilage can be almost stopped.

The freezing process alone is not a method of preservation. It is merely the means of preparing the fish for storage at a suitably low temperature and, in order to produce a good product, freezing must be accomplished quickly. A freezer requires to be specially designed for this purpose and thus freezing is a separate process from low temperature storage.

What happens during freezing

Fish is largely water, normally 60–80 percent depending on the species, and the freezing process converts most of this water into ice.

Freezing requires the removal of heat, and fish from which heat is removed falls in temperature in the manner shown in Fig. 1. During the first stage of cooling, the temperature falls fairly rapidly to just below $0^{\circ}C$, the freezing point of water. As more heat requires to be extracted during the second stage, in order to turn the bulk of the water to ice, the temperature changes very little and this stage is known as the period of "thermal arrest". When about three quarters of the water is turned to ice, the temperature again begins to fall and during this third stage most of the remaining water freezes. A comparatively small amount of heat has to be removed during this third stage.

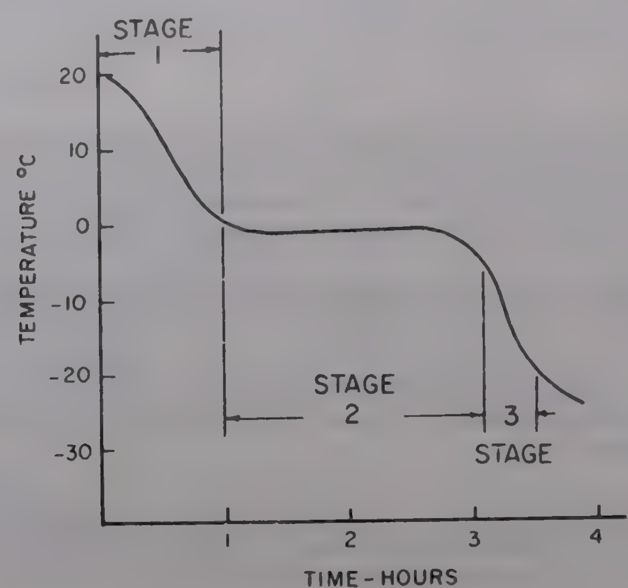

Fig. 1 Temperature–time graph for fish during freezing

As the water in fish freezes out as pure crystals of ice, the remaining unfrozen water contains an ever increasing concentration of salts and other compounds which are naturally present in fish flesh. The effect of this ever increasing concentration is to depress the freezing point of the unfrozen water. The result is that, unlike pure water, the complete change to ice is not accomplished at a fixed temperature of $0^{\circ}C$ but proceeds over a range of temperature. The proportion of water in the muscle tissue of fish which is converted to ice at various temperatures is shown in Fig. 2. The figure shows that by the time the fish temperature is reduced to $-5^{\circ}C$ about two thirds of the water is frozen. It also shows that even at temperatures as low as $-30^{\circ}C$, a proportion of the water in the fish muscle still remains in the unfrozen state.

Literature on the freezing of fish is confusing and often contradictory about what happens to fish as it freezes. This is particularly the case when reference is made to the difference between slow and quick freezing. One of the main reasons for this apparent confusion is that only in recent years has knowledge of the freezing process advanced sufficiently to explain these differences in freezing rates. The result is that much of the literature still in circulation is now outdated.

There was an early held opinion that rapid freezing was unsatisfactory since sudden cooling was thought to disrupt and tear the muscle tissue. It was also thought that, since water expands on freezing, it might be reasonable to expect the cell walls to burst under the pressure set up. There is some justification for both of these theories but they do not fully explain the differences between slow and quick freezing.

For some time, a widely held view was that slow freezing resulted in the formation of large ice crystals which damaged the walls of the cells. This would then result in a considerable loss of fluid when the fish was thawed. The smaller ice crystals formed, when fish is frozen quickly, were thought to do little damage to the cell walls and, as a result, little fluid was lost on thawing. Difference in size of ice crystal probably accounts for some of the differences between slow and quick freezing but it has been shown that this still does not provide a full explanation. The walls of fish muscle cells are sufficiently elastic to accommodate the larger ice crystals without excessive damage. Also, most of the water in fish muscle is bound to the protein in the form of a gel, and little fluid would be lost even if damage of the above nature did occur.

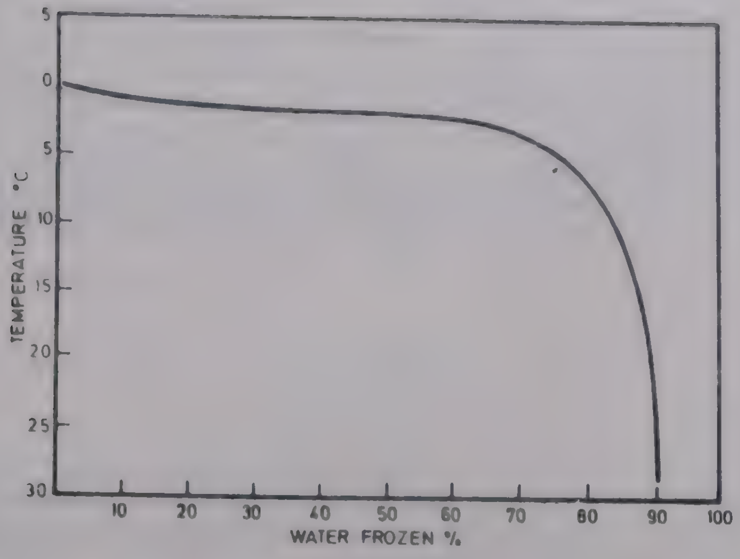

Fig. 2 Freezing of fish muscle. The percentage of water frozen at different temperatures

Slow freezing, however, does result in an inferior quality product and this is now thought to be due mainly to denaturation of the protein.

Changes take place in some fractions of the protein as a result of freezing and since they are altered from their "native" state they may be said to be "denatured" and hence, the term "protein denaturation". This denaturation depends on temperature and as temperature is reduced the rate of denaturation is reduced. Denaturation also depends on the concentration of enzymes and other compounds present. Thus, as the water is frozen out as pure ice crystals, the higher concentration of compounds in the unfrozen portion will result in an increase in the rate of denaturation. These two factors which determine the rate of denaturation act in opposition to each other as temperature is reduced and it has been demonstrated that the temperature of maximum activity is in the region of -1 to -2°C.

Slow freezing means that a longer time is spent in this zone of maximum activity and it is now thought that this factor accounts for the main difference in quality between slow and quick frozen fish.

<u>What is quick freezing?</u>

There is no widely accepted definition of quick freezing.

It is unlikely that even a trained taste panel could detect the difference between fish frozen in 1 h and 8 h but once freezing times begin to extend beyond 12 h difference may well become apparent. Freezing times of up to 24 h or even longer achieved in some badly designed and operated freezers will almost certainly result in an inferior product. Very long freezing times, such as those likely as the result of practices such as freezing fish by stacking in a cold store, may even result in spoilage by bacterial action before the middle of the stack is sufficiently reduced in temperature.

Since the temperature just below 0°C is the critical zone for spoilage by protein denaturation an early U.K. definition of quick freezing recommended that all the fish should be reduced from a temperature of 0°C to -5°C in 2 h or less. The fish should then be further reduced in temperature so that its average temperature at the end of the freezing process is equivalent to the recommended storage temperature of -30°C. With normal freezing practice in the U.K., this latter requirement is defined by stating that the warmest part of the fish be reduced to -20°C at the completion of freezing. When this temperature is reached, the coldest parts of the fish will be at, or near, the refrigerant temperature and the average temperature will then be near -30°C. This is a rather elaborate definition of quick freezing and it is probably more severe than is necessary to ensure a good quality product.

The more widely used definitions of quick freezing do not specify a freezing time or even a freezing rate but merely state that the fish should be frozen quickly and reduced in the freezer to the intended storage temperature.

The recommendation that the fish should be reduced to the intended storage temperature is important and this should be included in all good codes of practice for quick freezing. These two basic requirements for freezing, that the fish be frozen quickly and be reduced to storage temperature, go together since it is likely that a freezer which can quick freeze fish also operates at a sufficiently low temperature to ensure that the recommended product storage temperature can be achieved.

Some freezing codes and recommendations define freezing rate in terms of the thickness frozen in unit time. The freezing rate, however, is always quicker near the surface of the fish, where it is in contact with the cooling medium, and slower at the centre. Freézing rates are therefore, only average rates and they do not represent what happens in practice. Average freezing rates vary between 2 and 1 000 mm/h and to give the reader some idea what these rates represent in practice the range can be subdivided as shown in Table 1.

Table 1

Freezing rates

2 mm/h	Slow bulk freezing in a blastroom.
5 to 30 mm/h	Quick freezing in a tunnel air blast or plate freezer.
50 to 100 mm/h	Rapid freezing of small products.
100 to 1 000 mm/h	Ultrarapid freezing in liquefied gases such as nitrogen and carbon dioxide.

One exception to the general requirements for quick freezing of fish requires special mention. Frozen tuna, which will eventually be eaten in its raw state as the Japanese product "Shasimi" seemingly requires to be reduced to a lower temperature than other fish products. Japanese fishing vessels catching fish for this product operate with freezers at -50 to -60°C. Tuna is a large fish and when frozen whole by immersion in sodium chloride brine at a temperature of -12 to -15°C takes up to three days to freeze. Air blast freezing is now slowly replacing brine freezing for this purpose and operation with very low freezer temperatures can result in freezing times of about 24 h or less. The exceptionally low temperatures used in these freezers of about -50 to -60°C have given rise to conditions which require special precautions to be taken to avoid low temperature brittle fracture of metal structures in the vessels.

The above current requirement for air blast freezing tuna is one special case where general rules for quick freezing are not applied and it should be kept in mind that local requirements for particular products may, in some countries, give rise to others.

Double freezing

Double freezing means freezing a product, thawing or partly thawing it, and refreezing. This practice is often necessary for the production of some frozen fish products made from fish previously frozen and stored in bulk. What must be remembered is that even quick freezing results in quality changes in the fish and double freezing will therefore result in further changes. Only fish that were initially very fresh could therefore be subjected to double freezing and still conform to good quality standards. Fish frozen quickly at sea immediately after catching, for instance, would be suitable for this purpose.

Codes of practice

Most countries have legislation which relates to the handling and processing of foods in general and, where appropriate, this legislation will apply when handling fish before, during and after freezing. However, additional recommendations are often made, usually in the form of codes of practice, which, although not enforceable by law, can be rigidly applied by mutual agreement of all parties involved. Such codes of practice serve as a means of maintaining uniform standards based on good practice and take into consideration all relevant factors. In the absence of legislation, these codes of practice may also be quoted in cases of dispute as the minimum standards to be applied. Adoption of a code of practice is therefore an early step in the development of a freezing and cold storage industry.

For the wider aspects of freezing, codes of practice already exist which cover most of the likely requirements of a developing country with an expanding fish freezing industry. A number of these are listed below with a brief summary of their contents.

Code of Practice for Frozen Fish, FAO Fisheries Circular No. 145 (Revision 2) 1977. General advice in English, French and Spanish on the production, storage and distribution of frozen fish. The code covers the freezing of fish at sea and on shore and it also deals with cold storage, packaging, transport and thawing of frozen fish and fish products. The code does not cover all the potential variations in freezing and cold storage practice but the information given can form the basis for more specialized codes which can take into account local and national requirements.

This code of practice is a companion document to this one, and each complements and supplements the other.

This code of practice for frozen fish will eventually be published as a recommended international code by Codex Alimentarius.

OECD/IIR Draft Code of Practice for Frozen Fish, 1969. Produced in an English-French edition it gives guidance on quality and handling at all stages of the processing of fish into a frozen product. The code covers a wide range without becoming too involved in details. (OECD = Organization for Economic Cooperation and Development, Paris; IIR = International Institute for Refrigeration, Paris)

Recommendations for the Processing and Handling of Frozen Foods, IIR, 1972 (2nd Edition). Produced in a combined English-French edition, the document is concerned with all kinds of frozen foods including fish and fish products. It deals with principles and with basic and applied problems, and is intended as a guide for international and national organizations. In many ways, it is similar in content to this document but since it covers all frozen food products, it has a wider application.

Guide to Refrigerated Storage, IIR, 1976. Produced in a combined English-French edition, the document is a comprehensive and detailed guide covering all aspects of the design, construction and operation of cold stores. It is in a form which may be used for technical and practical study of cold storage and it can also be used commercially to make improvements in one of the most important links of the chain of refrigeration, namely refrigerated storage.

Codex Alimentarius Commission Joint FAO/WHO Food Standard Programme. The main aims of the Commission are to recommend product standards for international uniformity and to provide advice on how to meet such standards by issuing codes of practice. Relevant codes and standards should therefore be the starting point for all national and local codes and allowance made, if necessary, for differences that cannot be resolved due to legal or other factors. These codes and standards are often detailed and may refer to only one species or product. Until final acceptance by The Codex Alimentarius Commission, the codes are available as FAO Fisheries Circulars.

National codes of practice. The majority of developed countries with well established fisheries have codes of practice and guidelines for their own fishermen, processors, retailers and other interested groups involved in the handling and processing of frozen fish and fish products. It would be advisable for the authorities in developing countries to study these. They will give guidance for the formulation of new codes. In addition, a study of the codes will ensure that any new standards will be in accord with the standards of customers for frozen fish exports.

Most codes of this type are formulated and issued by the appropriate agricultural, food or fisheries division of national or state governments.

Handling of fish before freezing

Freezing and cold storage is an efficient method of fish preservation but it must be emphasized that it does not improve product quality. The final quality depends on the quality of the fish at the time of freezing as well as other factors during freezing, cold storage and distribution.

The important requirement is that the fish should at all times be kept in a cool condition, about 0°C, and the use of ice or other methods of chilling is recommended.

The FAO document "Ice in Fisheries" FAO Fisheries Report No. 59 (Revision 1) 1975 describes in detail the methods of using ice or refrigerated sea water to cool fish.

Apart from keeping the product chilled, it is also essential to adopt a high standard of hygiene during handling and processing to prevent bacterial contamination and spoilage.

The "Recommended International Code of Practice for Fresh Fish", CAC/RCP 9, 1976 issued by the Codex Alimentarius Commission and its companion document the FAO "Code of Practice for Frozen Fish" give guidance on this aspect of quality control.

Advice on handling fish before freezing at sea is given in Chapter 8.

In some countries chemicals are currently used to treat fresh fish in order to assist with such things as colour retention and the retention, or even addition, of fluids. The treatment of food with chemicals is usually subject to national and local restrictions and it would be inappropriate to make any general comment on their use in this document.

Frozen fish products

The variety of species, processes, methods of presentation and packaging available provide scope for the preparation of numerous frozen fish products. These products, however, can be separated into two main groups, products intended for direct consumption and products intended for further processing.

Products for direct consumption. Individually quick frozen (IQF) products are fish products which have been frozen as single units and which need not be thawed for subdivision or for cooking purposes. IQF single fillets and shrimp are two products of this type.

The demand for IQF products has increased with the upsurge in the number of low temperature "freezer" cabinets both in catering establishments and in the home. IQF freezing allows for the purchase of a frozen product in bulk and the selection from storage of only sufficient quantities to meet immediate requirements.

Other products such as small packages, cartons, blocks of fish and fish portions are also produced for direct consumption without the need for reprocessing. The consumer will purchase this type of product from the retailer, still in the frozen state, and either cook it in the frozen state or thaw it for immediate consumption. In this latter case, the consumer does not require low temperature storage.

The production of products for direct consumption may not yet be appropriate in many developing countries. This type of product requires the provision of an extensive network of refrigerated storage and transport. This facility, which is popularly known as the "cold chain", may not be developed fully enough to enable this system to operate.

Products for further processing. These products are produced for two purposes.

(1) The product is frozen in bulk and when thawed after storing, can be used in the many ways that newly caught, unfrozen fish may be used.

(2) The product is frozen in bulk and after storage it may be further processed without thawing so that it may be presented as a retail pack.

Products frozen in bulk can be unprocessed, such as blocks of whole fish frozen in contact freezers. Blocks of frozen fish may weigh up to 50 kg; they are usually glazed or wrapped after freezing and are then stored until required for further processing.

In some cases, fish are bulk frozen, stored and finally thawed all in one place. This is usual when there is a short seasonal fishery and fish are preserved for processing over a longer period. Bulk frozen fish may also be distributed in the frozen state. This enables the fish to be sold to a larger home market and also allows the product to be exported. In this case there is an additional requirement for low temperature transport and a more extensive cold chain.

Fish frozen in bulk may also be fully processed before freezing and only the skinless, boneless portion used. One particular process of this type worth special mentioning is the production of frozen fillet blocks. A frozen fillet block is a regular shaped block of fish flesh frozen in a horizontal plate freezer within a treated cardboard carton and a metal retaining frame (Fig. 3). Special care is taken to ensure that there are no voids in the block, and skilled operators and special techniques are therefore required. After freezing, the blocks may be stored in bulk and at a later date cut into smaller portions of different shapes.

The fish portions may then be packaged and sold in this form or they may be coated with a flour batter and breadcrumbs. Coated fish portions should be returned to the freezer and rehardened before packaging and storing.

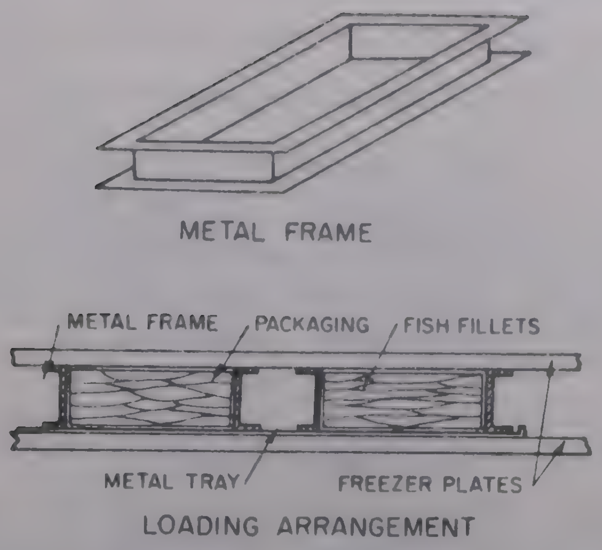

Fig. 3 Packaging and loading arrangement for making fillet blocks in a horizontal plate freezer

The type of frozen fish product and the form in which it is produced in a particular country may well depend on the extent of the cold chain as well as on the demands of the consumer. It therefore seems likely that in most developing countries a bulk freezing process will be the initial development. This will enable the industry to cater for seasonal variations and allow a wider distribution of the fish catch. Other frozen products will follow later when the industry develops and the cold chain is extended.

2. FREEZERS

There are now many different types of freezer available for freezing fish, and freezer operators are often uncertain about which type is best suited to their needs.

Three factors may be initially considered when selecting a freezer; financial considerations, functional considerations and feasibility.

Financial considerations will take into account both the capital and running cost of the equipment and also likely losses such as product damage and dehydration. Expensive freezers should therefore justify their purchase by giving special benefits and, if these benefits are not worthwhile, they may not need to be considered.

Functional considerations will take into account such things as whether the freezer is required for continuous or batch operation and also whether the freezer is physically able to freeze the product. For instance, a horizontal plate freezer would be inappropriate for freezing large whole tuna.

Feasibility will take into account of whether it is possible to operate the freezer in the locality of the plant. A liquid nitrogen freezer (LNF), for instance, may be suitable in every respect for freezing the product and the high costs of using this method of freezing may be justified. However, if the location of the plant is such that there can be no guaranteed supply of liquid nitrogen, the freezer should not be considered.

Initial considerations such as those mentioned above will eliminate many freezers from the final choice but still leave many options open to the freezer operator. The final selection will depend on the individual circumstances and to enumerate all the possibilities would be an endless task. In order to give the reader some guidance in both selection and use of freezers, descriptions of the various types now available for freezing fish are given. The types of freezer likely to be used in developing countries, especially where freezing is a relatively new process, are those that have already been widely used for freezing fish and have therefore been well tried and tested. Freezers in this category are described more fully than others.

Types of freezer

The three basic methods of freezing fish are:

(1) Blowing a continuous stream of cold air over the fish - air blast freezers.

(2) Direct contact between the fish and a refrigerated surface - contact or plate freezers.

(3) Immersion in or spraying with a refrigerated liquid - immersion or spray freezers.

Air blast freezers. The big advantage of the blast freezer is its versatility. It can cope with a variety of irregularly shaped products and whenever there is a wide range of shapes and sizes to be frozen, the blast freezer is the best choice. However, because of this versatility it is often difficult for the buyer to specify precisely what work he expects it to do and, once it is installed, it is all too easy to use it incorrectly and inefficiently.

Before going on to describe the various types of air blast freezer, it is necessary to deal with some of the basic principles of air blast freezer design and operation.

Designing air blast freezers. The use of air to transfer heat from the product being frozen to the refrigeration system is probably the most common method used in commercial refrigeration. The natural convection of the air alone would not give a good heat transfer rate, therefore, forced convection by means of fans has to be introduced. To enable the product to be frozen in a reasonable time the air flow rate should be fairly high. Also, in order to obtain uniform freezing rates throughout the freezer, the air flow requires to be substantially the same over each fish or package.

Examination of Fig. 4 shows that at very low air flow rates the freezing time is long. A single fillet for instance will take 4 times as long to freeze in the relatively still air in a cold store as it would in a properly designed air blast freezer. Fig. 4 also shows that at high air speed, which also means high fan power, freezing times will change very little with further increases in air speed. A design air speed of 5 m/s has been found to be a good compromise between slow freezing rates and high fan costs and this air speed is recommended for most air blast freezers.

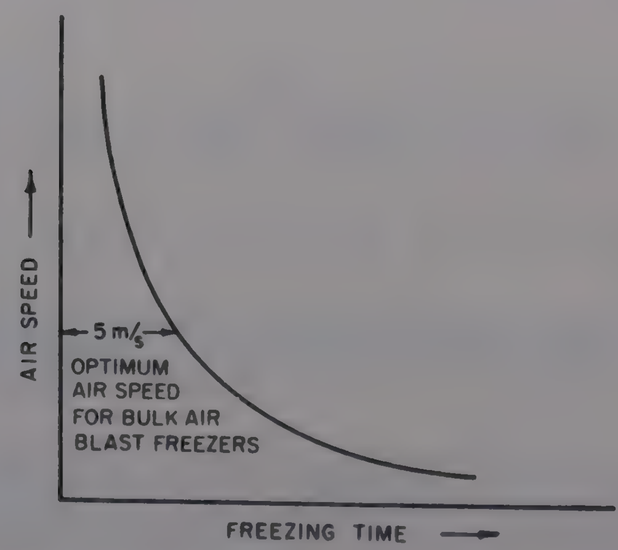

Fig. 4 Variation of freezing time with air speed in an air blast freezer

Continuous air blast freezers may economically justify air speeds in excess of the above-recommended value. Continuous freezers are expensive and require a good deal of floor space. If the air speed is increased and the freezing time reduced, a smaller freezer will be required for a given freezing capacity. The savings in freezer costs may therefore justify the use of higher air speeds. Air speeds as high as 10 to 15 m/s may therefore be economically justifiable for continuous freezers.

The air flow over the surface of a product being frozen cannot be measured. In reality the air adjacent to the surface of the product is usually stagnant due to the friction between the air and the surface of the product. This stagnant air forms a boundary layer which acts as a resistance to heat

tranfer and its thickness depends on air velocity, degree of turbulence and other factors. The air speeds quoted for air blast freezers are therefore only average speeds for the spaces between the fish or packages of product being frozen. A simple example which shows how this average air speed is derived is shown diagrammatically in Fig. 5.

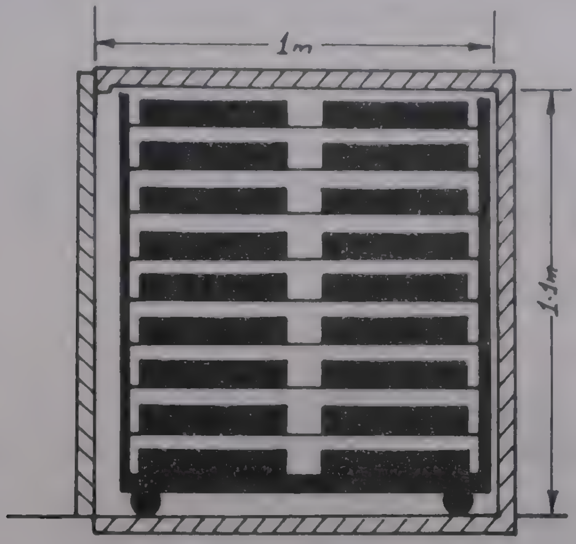

Fig. 5 Calculation of average air speed in an air blast freezer

Calculated cross sectional area of tunnel, 1.1 x 1.0	= 1.1 m^2
Calculated cross sectional area of produce and trolley (shaded areas)	= 0.7 m^2
Air flow (obtained from fan rating or measured in open part of tunnel)	= 2.0 m^3/s
Calculated average air velocity, $\frac{2.0}{1.1 - 0.7}$	= 5 m/s

Another aspect of air flow rate that has to be considered in the design of a freezer is the permitted temperature rise over the product. If the temperature rise is too great, there will be differences between the freezing times of products placed upstream and downstream in the freezer space. The differences in freezing time can be calculated by the method shown in Chapter 3. If the air temperature rise in the freezer is too small then it is likely that the freezer design is poor, and more powerful fans than necessary are being used to maintain the recommended air speed. In other words, the quantity of air being circulated is too high. Fig. 6 shows examples of good and bad freezer layouts which demonstrate this point.

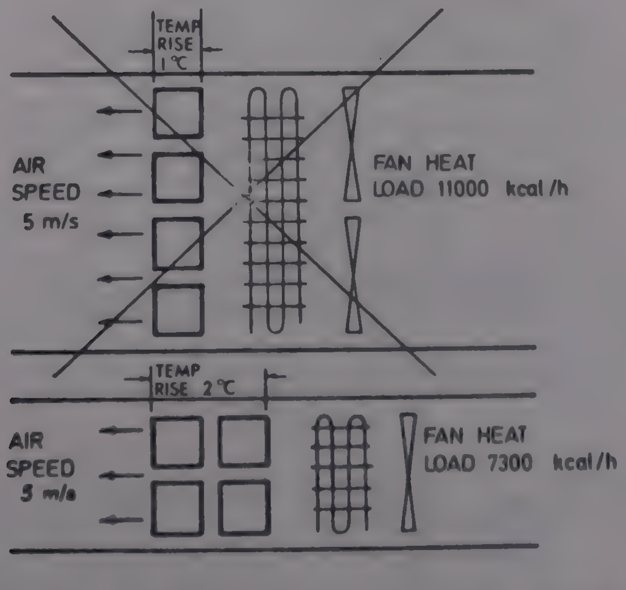

Fig. 6 The effect of different loading arrangements on the fan requirements for an air blast freezer

Even in a well designed air blast freezer, the fan load can account for 25 to 30 percent of the refrigeration requirement and in a poor design it has even been known for the fan load to exceed the product load. No firm recommendation can be made about the permissible rise in temperature but an average air temperature rise of 1 to 3 degC is reasonable and may be used as a guide. This temperature rise will depend on the heat load; therefore it will be higher at the start of a freeze than at the end. The average temperature rise is therefore calculated from the total heat extracted from the fish and the weight of air circulated during the freezing period. The following sample calculation is used by way of illustration:

Weight of fish frozen		100 kg
Heat to be extracted	90 x 100 =	9 000 kcal
Freezing time		2 h
Fan circulation rate		150 m^3/min
Density of air		1.45 kg/m^3
Weight of air circulated during freezing	150 x 60 x 2 x 1.45 =	26 100 kg
Specific heat of air		0.24
Average rise in air temperature	$\frac{9\ 000}{26\ 100 \times 0.24}$ =	1.44 degC

Many of the faults of air blast freezers can be attributed to insufficient or non-uniform air flow over the product.

Air must be directed to flow uniformly over the product and not merely be blown into the freezer space and hopefully be expected to find its own way to where it is required. Air will normally take the path of least resistance and many of the faults of air blast freezers are due to the low resistance paths that are available which allow the air to be diverted from its main work – transfer of heat from the surface of the product.

An air blast freezer fan will only work effectively if it is correctly mounted as shown in Fig. 7. The clearance between the fan and the mounting plate should only be a few millimetres.

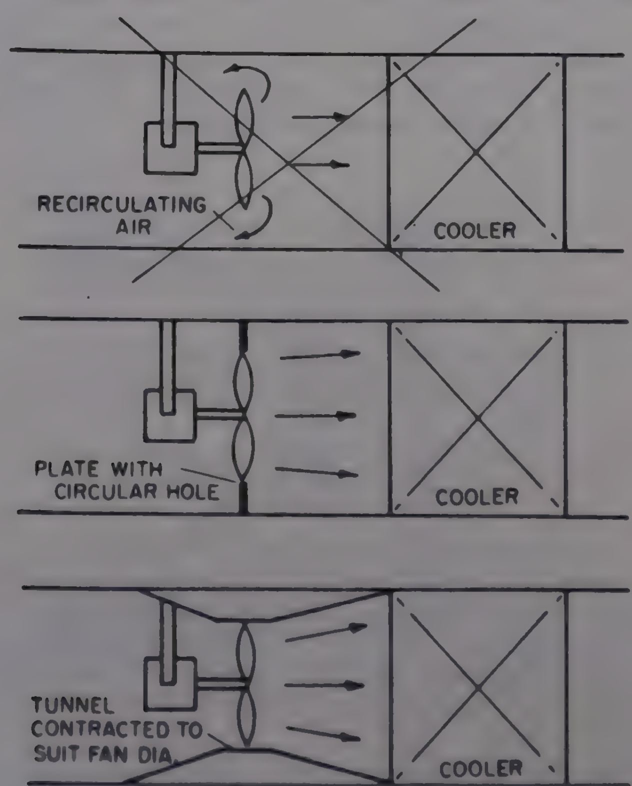

Fig. 7 Bad and good fan mounting arrangements for tunnel air blast freezers

Given a free choice, the designer should always position the fan before the cooler. The cooler provides a relatively high resistance to air flow and this helps to even out the flow. Air leaving a radial fan is also imparted with a swirling motion and the fins of the cooler act as a flow-straightener.

When air changes direction in the freezer, there are difficulties in maintaining uniform distribution, and air flow over the product may be variable (Fig. 8). There are a number of ways of solving this problem by using vanes, baffles and plenum chambers. In Fig. 9 the air is shown to be correctly distributed by using suitably designed and properly spaced turning vanes. The air may also be redistributed by means of baffles which are spaced so that the pressure resistance across the section results in an even flow (Fig. 10). It is difficult to predict the exact pattern required for correct redistribution of the air, and to compensate for this the baffles are often made adjustable. This method adds to the total resistance of the system and may mean higher fan power and additional costs. The method however is very simple, allows for readjustment on site and therefore is well worth considering.

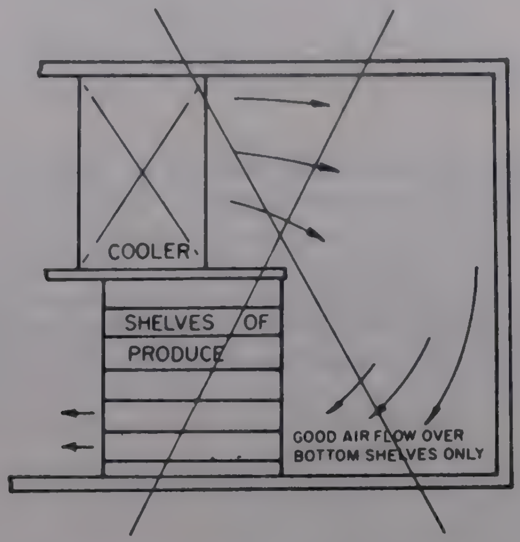

Fig. 8 Poor air distribution in a tunnel air blast freezer

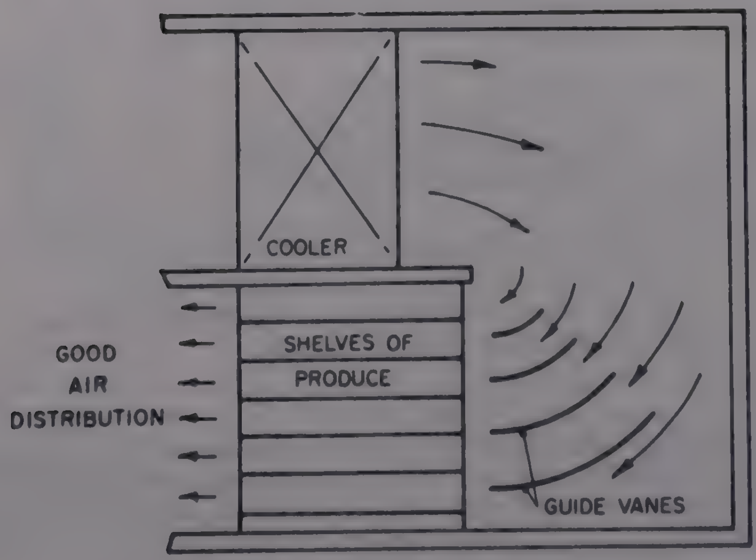

Fig. 9 Good air distribution in a tunnel air blast freezer using guide vanes

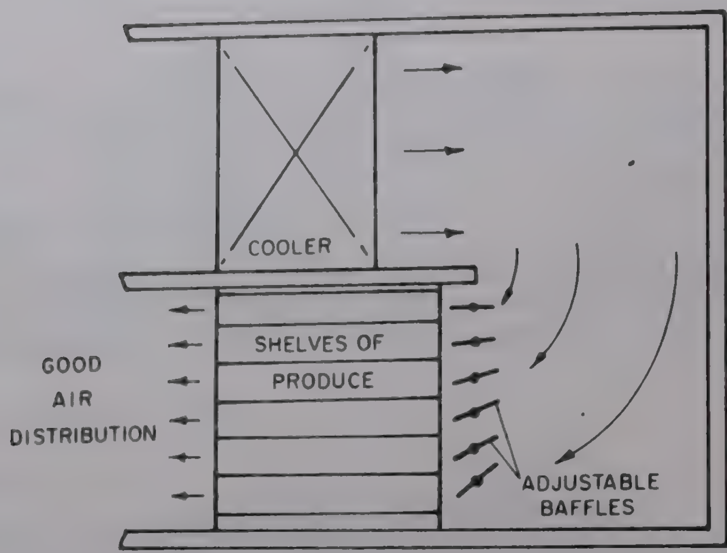

Fig. 10 Good air distribution in a tunnel air blast freezer using adjustable baffles

The third method of readjusting the air flow is to incorporate a plenum chamber (Fig. 11). This reduces the effects of high air velocities and gives a more uniform air flow. This system works well if the product imposes a comparatively high resistance to the circulation of the air.

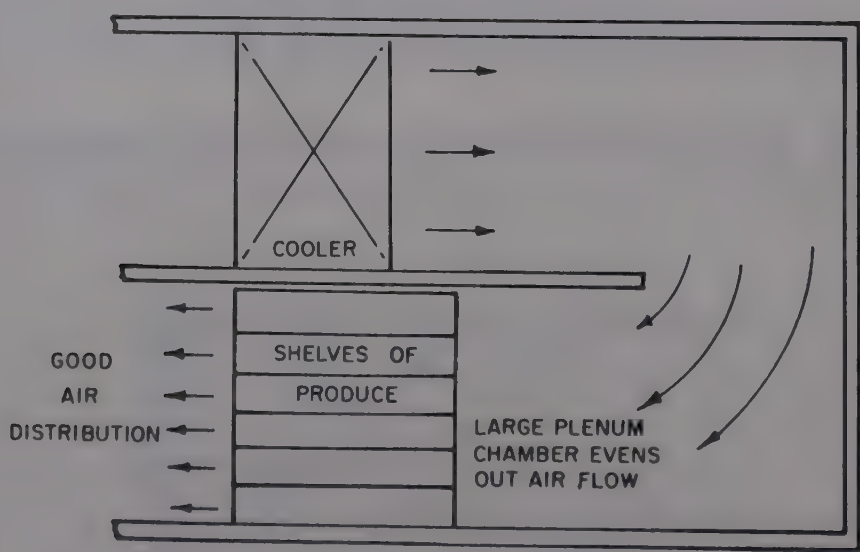

Fig. 11 Good air distribution in a tunnel air blast freezer using a plenum chamber

Air flow over the cooler is equally as important as air flow over the product. As already mentioned, the cooler acts as an air-straightener and air distributor. There are however limitations to how effective this may be, and often, more than one cooler fan is needed to ensure a uniform distribution of air over the cooler surfaces.

Nearly all air blast freezers operate with finned tube coolers. The fins greatly extend the surface for heat exchange, and the closer the fins the greater will be the surface area and the smaller the cooler unit. Moisture lost from fish during freezing and from air infiltrating into the cooler will eventually be deposited as frost on the cooler surface. If this frost eventually bridges the space between the fins, the effective cooler surface is reduced and the freezer temperature will rise. There will also be a greater resistance to air flow through the cooler and the air flow rate may be reduced.

Most of the water lost from the fish is lost during the early stages of freezing and in some freezer designs, this will mean a higher degree of frosting on some parts of the cooler than on others. This will effectively reduce the period of operation before a defrost is necessary. Frost build-up on the cooler is also more prolific on the front, upstream coils; therefore a cooler with a large frontal area will be able to operate longer before a defrost is necessary. The fin spacing may also be increased where there is likely to be a quick build-up of frost.

A good freezer design should be able to operate for at least 8 h before a defrost is required but a poor design may require defrosting every 2 h.

Types of air blast freezer. There are many different designs of air blast freezer both for batch and continuous operation. Details are given of a number of types of air blast freezer in common use, with comment on their suitability for various products and methods of processing and also on their limitations.

Continuous air blast freezers. In this type of air blast freezer, the fish move through the freezer usually entering at one end and leaving at the other.

Fish may be moved through the freezer on trucks or trolleys or they may be loaded on a continuously moving belt or conveyor.

When trucks or trolleys are used, they are loaded at one end of the freezer and progressively moved along the freezer as additional trucks are loaded. Once the freezer is full, a truck has to be removed from the exit end before a fresh truck can be loaded. This batch-continuous operation must always allow the coldest air to flow over the coldest fish; otherwise fish which are well frozen will be heated again as new trucks are loaded. The movement of the trucks in Fig. 12 is therefore in the opposite direction to the air flow in the freezing section. One difficulty with this type of freezer is that when the freezer is fully loaded, a whole row of trucks has to be moved at one time. This is particularly difficult at very low temperatures since special bearings and lubricants are required for the truck wheels and it is difficult to keep the trucks free of frost and ice. Trolleys have been suspended from overhead rails to overcome some of these difficulties but this equipment is cumbersome and still not easy to operate.

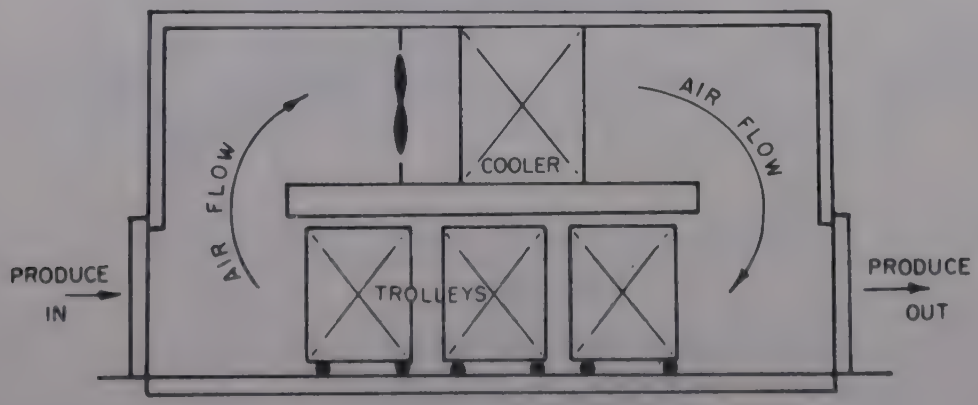

Fig. 12 Batch-continuous air blast freezer with counterflow air circulation

To avoid moving trucks within the freezer, a batch-continuous freezer can be designed with a cross flow air arrangement and the freezers may then be loaded from the side as shown in Fig. 13. Again in this freezer, once it has been fully loaded, a truck is removed before a fresh one is added. It is a simple matter to keep account of the loading sequence of the freezers by having hand-set clock dials above each entrance which will indicate the time the truck or trolley will be ready for unloading. This cross-flow arrangement allows a cooler with a large frontal area to be built, and frost is also deposited uniformly.

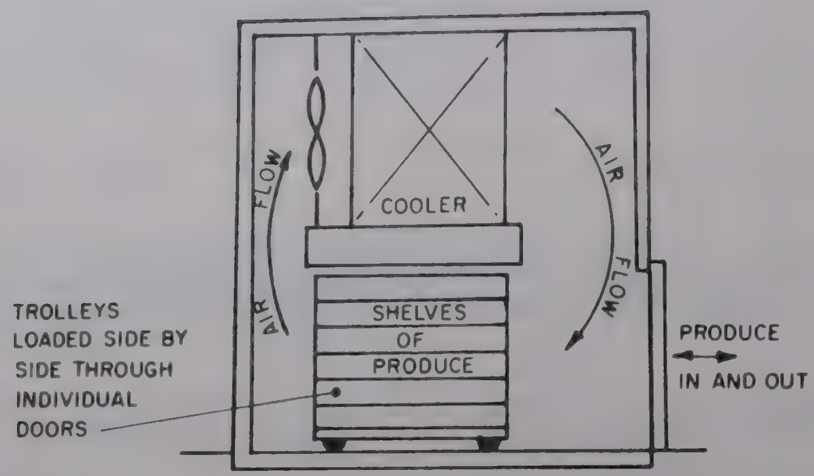

Fig. 13 Batch-continuous air blast freezer with crossflow air circulation

Continuous air blast freezers using belts or conveyors for moving the product through the freezer can only be used if the product can be frozen quickly (Fig. 14). It is unlikely that a product with a freezing time of more than 30 min would be suitable for this freezer. The reason for the limitation on freezing time is that the freezer will become too long and cumbersome if a long freezing time is required. The freezing time, the freezing requirement in kg/h and the loading density of the product on the belt determine the freezer dimensions.

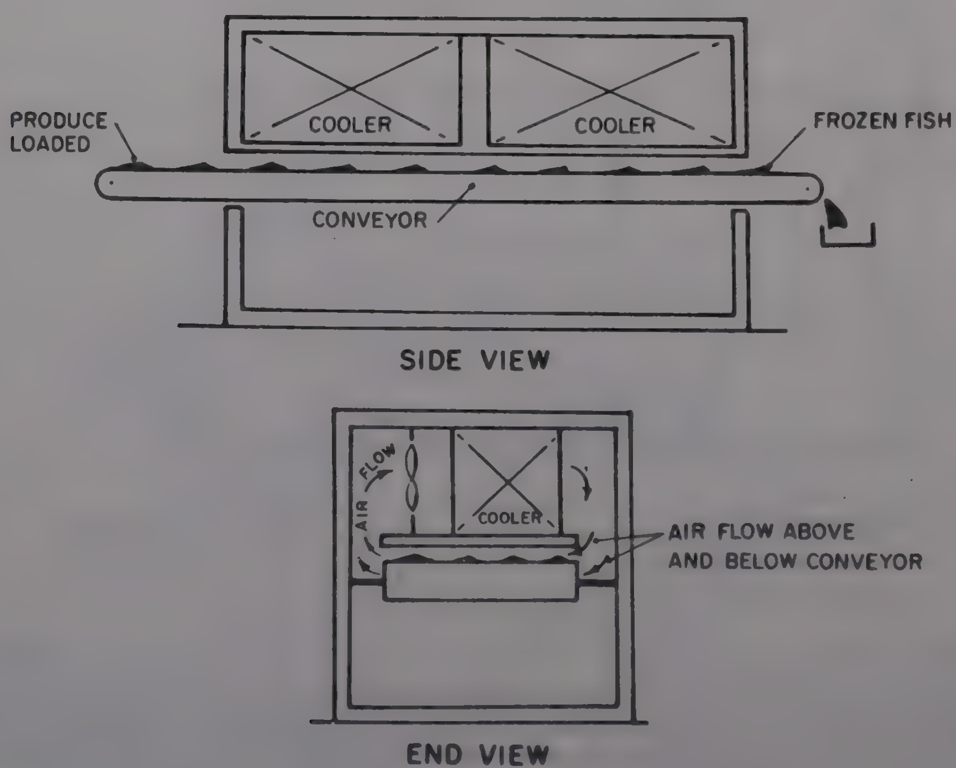

Fig. 14 Continuous belt air blast freezer with crossflow air circulation (also constructed with countercurrent series flow air circulation)

The following example shows how this calculation is made:

Freezing requirement		200 kg/h
Freezing time		20 min
Load on belt	$200 \times \frac{20}{60}$ =	66.6 kg
Belt loading density		3 kg/m^2
Belt width		1 m
Belt loading per unit length	$\frac{3}{1}$ =	3 kg/m
Belt length	$\frac{66.6}{3}$ =	22.2 m

Allowing for loading and unloading of the fish outside the freezing space, the length of the freezer required for the above requirement would be about 25 m.

The space required for a continuous belt freezer can be reduced if a double or triple belt is used (Fig. 15), or if the belt is arranged in the form of a spiral (Fig. 16).

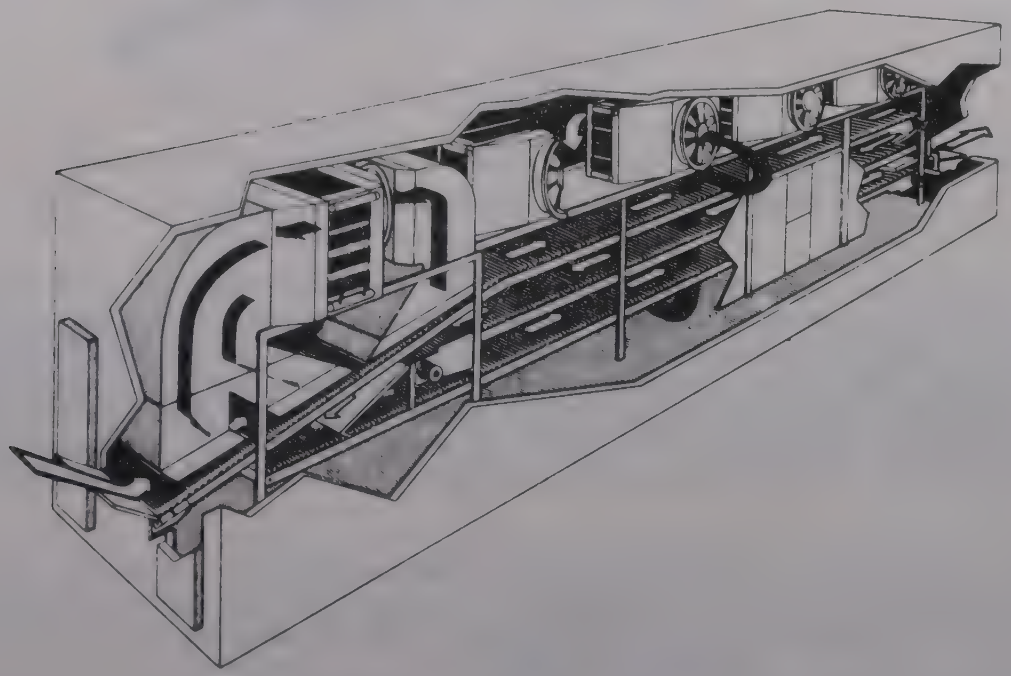

Fig. 15 A triple belt air blast freezer

Fish in direct contact with an open mesh belt cannot be readily transferred to another belt when they are partially frozen. Double belt and triple belt freezers are therefore only suitable for certain products such as battered and breaded fish portions, unless certain features are built into the design of the freezer. The semi-fluidized freezer described later is a freezer specially designed for this method of operation.

Spiral belt freezers are made in a variety of designs and are widely used for IQF products. Some difficulties, however, have been experienced in their use. Excessive drip from the fish onto the belt before freezing results in ice being formed between the links and when the belt folds around the spiral, a considerable strain is put on the links. Fish frozen on this belt also tends to wrinkle, again due to the curvature of the belt.

Continuous belt freezers, generally, have their own special problems. The belt has to be flexible, easily cleaned, noncorrosive, suitable for use in direct contact with food and should not interfere unduly with either the freezing time or adversely affect product quality. Stainless steel mesh link belts or chain link belts are mainly used for this purpose but they have certain disadvantages. Apart from being expensive, stainless steel mesh and link belts affect the appearance of the product. If fish are loaded directly on the belt, the crinkled or indented appearance of the frozen product is not always acceptable. Open mesh belts also give rise to difficulty when removing the product after freezing, and

some weight loss may be incurred due to slight physical damage. Skin-on fillets can usually be removed quite easily but skinless fillets and fish portions tend to stick to the belt and unacceptable weight losses are likely.

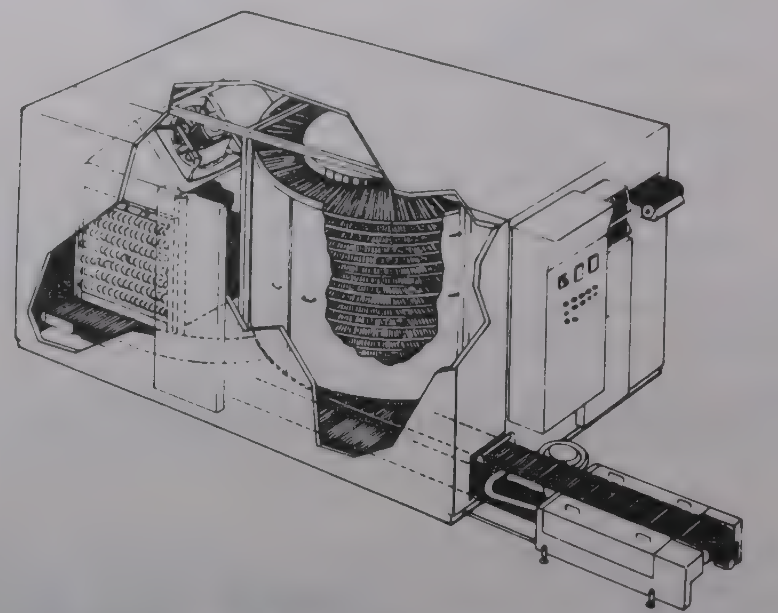

Fig. 16 Continuous air blast freezer with the belt arranged in a spiral

Plastic belts made in the form of interlocking links have been used in some continuous freezers. This type of belt, due to its open mesh construction, only adds about 10 percent to the freezing time. If they are only used for the initial part of the freezer, the fish can be surface-hardened and then be transferred to a stainless steel belt. This would allow a two-belt operation in the freezer. Plastic belts have a rather open mesh and would not be suitable for some small products and where indentations on the surface of the fish are undesirable. In spite of these often minor difficulties in obtaining an ideal belt for continuous belt freezers, many are successfully operated for freezing a variety of products.

Continuous belt freezers can be constructed with either cross-flow or series-flow air circulation. In the series-flow arrangement, the direction of air flow must be such that the coldest fish meet the coldest air. The design of the belt entry and exit must keep the rate of air infiltration to a minimum.

In a continuous freezer, there is no scope for rearranging the volume or space for different products. The belt speed, however, is usually variable and this can be adjusted to accommodate different product freezing times. The capacity of a continuous freezer can therefore vary considerably depending on the product being frozen and its freezing time. Table 2 is a freezer capacity list supplied by the manufacturer of one type of continuous freezer and it clearly shows there is a wide variation depending on the type of product being frozen.

Table 2

Variations in the capacity of a continuous freezer

Product	Product thickness (mm)	Capacity (kg/h)
Plaice fillets	10	100
Cod fillets	18	85
Shrimp (whole)	9	55
Shrimp (meats)	8	150

Another important consideration when using a continuous air blast freezer is whether the freezer will be used continuously. A continuous freezer left in operation but not fully loaded will give rise to higher freezing costs per kg of product frozen.

<u>Batch air blast freezers</u>. Batch air blast freezers use pallets, trolleys or shelf arrangements for loading the product. The freezer is fully loaded, and when freezing is complete, the freezer is emptied and reloaded for a further batch freeze. Apart from this difference in mode of operation, the batch freezer gives rise to bigger fluctuations in the refrigeration load than continuous or batch-continuous freezers (Fig. 17).

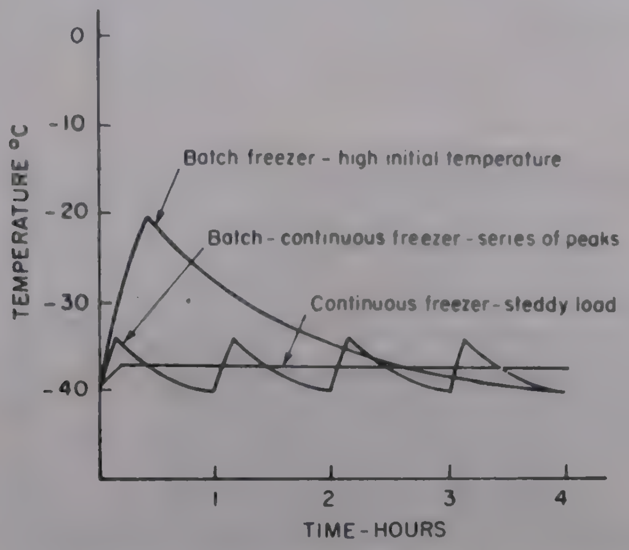

Fig. 17 Freezer operating temperatures for different types of air blast freezer

This large fluctuation in refrigeration requirement means that the refrigeration system will require special control arrangements to cater for the changing load. Capacity control or a multi-unit system can be used or a competent engineer can manually control the system to match the load. Some refrigeration systems are also better suited to this type of variable load application than others.

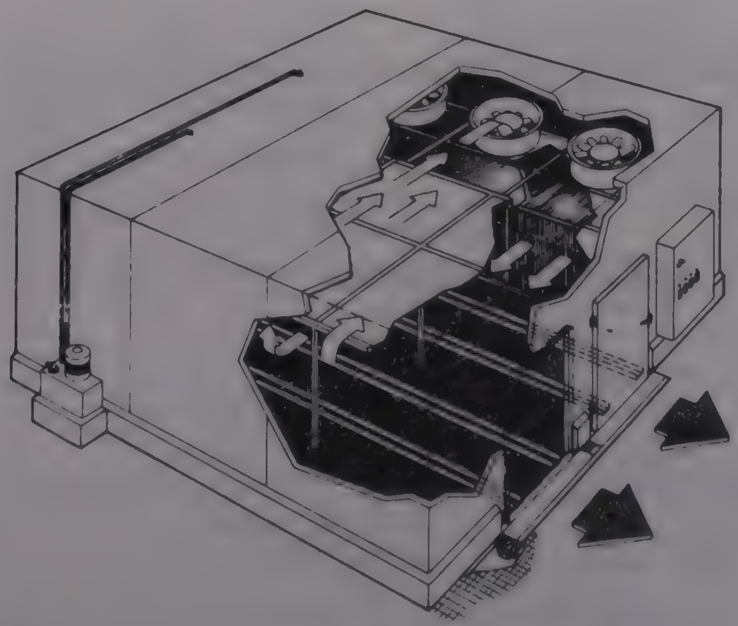

Fig. 18 Factory assembled air blast freezer with push through tunnel for two rows of trucks

It is seldom that fish processing can be arranged so that all the fish can be loaded into a batch freezer at the same time. Therefore, if each trolley or pallet is loaded as and when it is ready, the refrigeration peak load will be considerably reduced. This will make the operation similar to a batch-continuous process, but again, care should be taken not to place warm fish upstream of a partly frozen product.

The freezer shown in Fig. 18 is a batch tunnel freezer with a push-through arrangement for two lines of trucks. If this design of freezer was used with a batch-continuous operation, warm fish could be loaded upstream of partly frozen fish. This freezer should therefore only be fully loaded and operated as a batch freezer.

Another batch freezer arrangement is shown in Fig. 19. In this model, the trolleys are loaded from the side of the freezer and the air flows across the three freezers in line. Again, if this type of freezer is operated as a batch-continuous freezer, warm fish could be loaded upstream of partly frozen fish. The freezer should therefore be fully loaded at the start of each freeze.

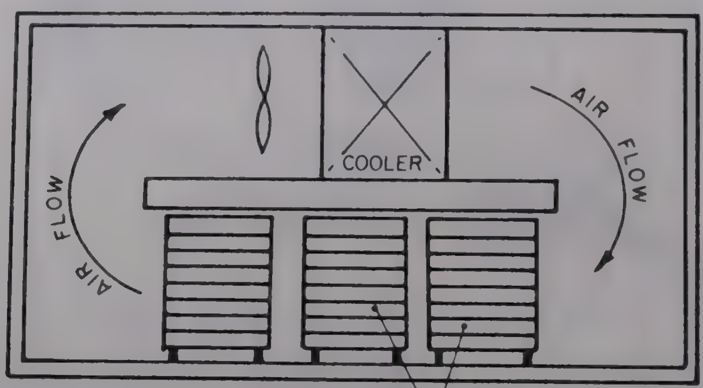

Fig. 19 Batch air blast freezer with side loading and unloading

In some air blast freezers, the cooling coil can be at the same level as the working section (Fig. 20). This is a fairly good arrangement since the cooler acts as a diffuser and evens out the air flow immediately before it is directed over the fish.

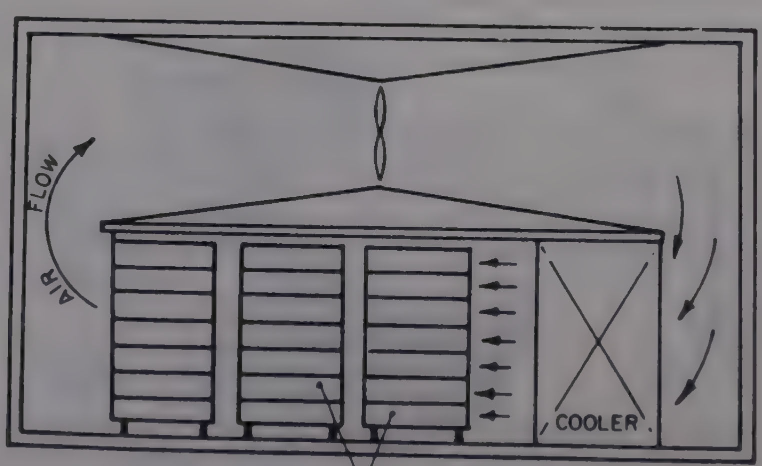

Fig. 20 Air blast freezer arrangement showing the cooler acting as an air diffuser

It can be seen that there is a wide variety of air blast freezer arrangements to suit the requirements of different layouts, operating methods and freezing systems.

Some air blast freezer designs are not suitable and some of the faults that give rise to long freesing times are shown in the series of diagrams (Figs. 21 to 24).

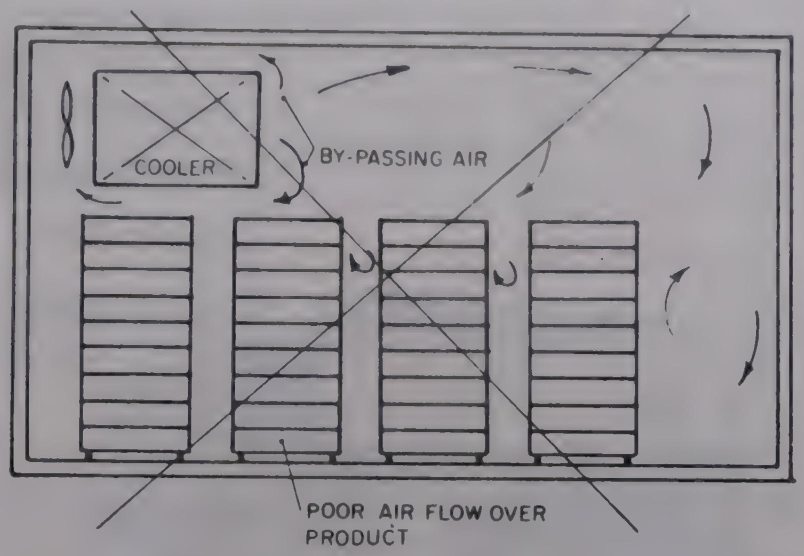

Fig. 21 Room freezer with poor air flow over the surface of the product

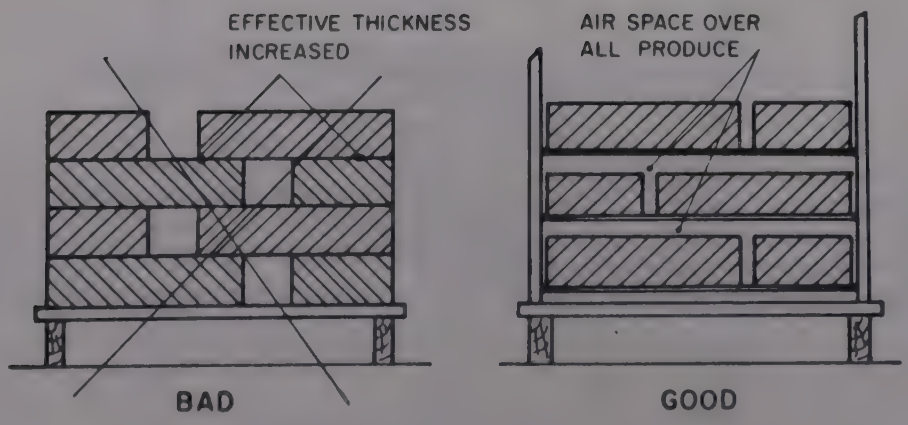

Fig. 22 Bad and good loading arrangements for freezer trolleys and pallets

The freezer arrangement shown in Fig. 21 is typical of many room freezers that are built. The cooler unit may be mounted at roof level, as shown, or may be a floor-mounted unit. There is no special means of directing the air over the fish and therefore it generally tends to swirl about in the empty spaces in the room and not flow between the shelves or trays loaded on the pallets. The reason for this is that the air takes the path of least resistance and does not readily flow through the comparatively narrow spaces between the product. The air must be ducted so that it has no alternative but to flow over the fish. This is an extremely important feature of a tunnel air blast freezer. Many of the diagrams shown earlier have good layouts which show this.

The method of stacking shown in Fig. 22 means that the effective thickness of the product to be frozen is increased. This will, in turn, result in long freezing times. When this type of package is to be frozen, either a shelf arrangement should be used as shown or spacers should be used correctly as shown in Fig. 23.

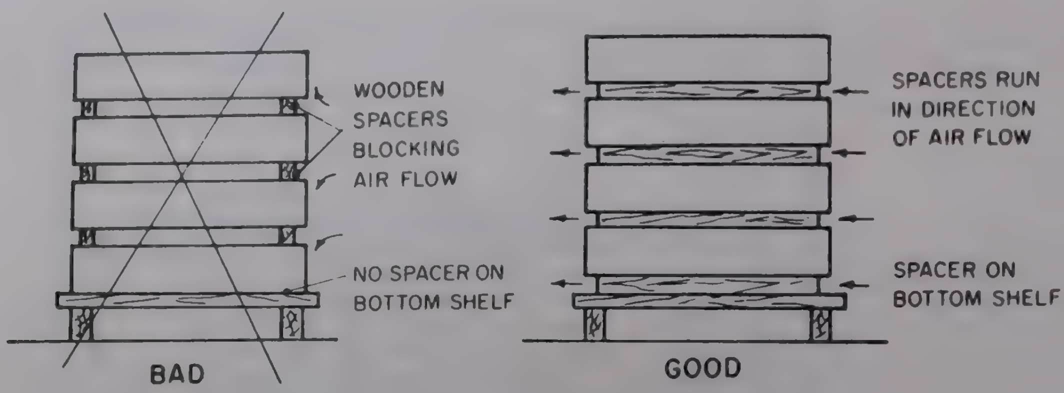

Fig. 23 Bad and good use of spacers when stacking produce for freezing

The incorrect method of loading the pallet shown in Fig. 23 seems hardly credible but is often used in commercial practice. The mistake can easily be made by an operator who does not observe the direction in which the battens on the base of the pallet are running. Some directional marking on the top of the pallet base may be advisable.

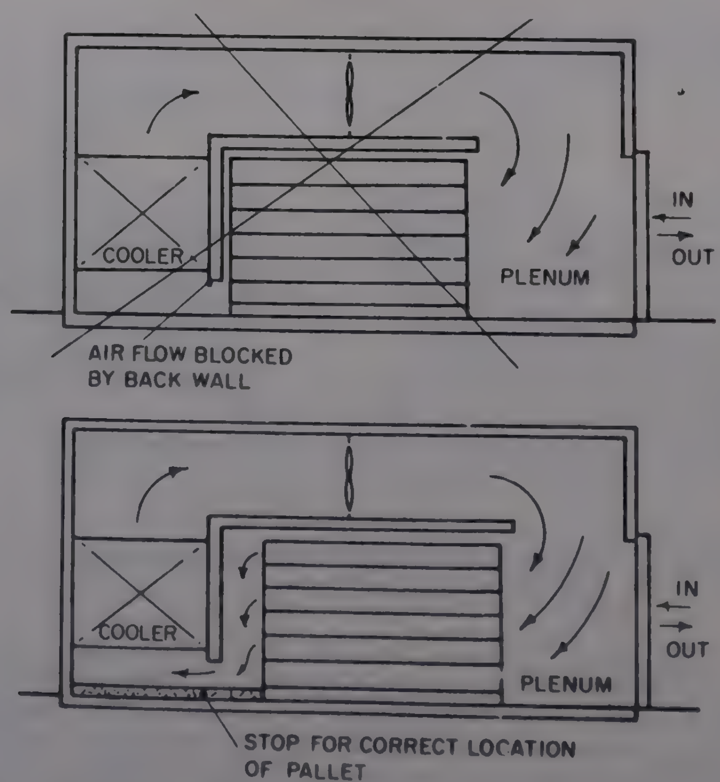

Fig. 24 Bad and good pallet positioning in an air blast freezer

The fault shown in Fig. 24 can happen if there is no positive location of the pallet in the freezer space. In this case the pallet has been pushed in until it reaches the back wall. An effective solution is to provide a stop, as shown in the corrected arrangement. This is not a particularly good design

of freezer but the illustration is given to show that it can be made completely ineffective due to a small omission in the design.

Poor air flow over the fish but good air flow through the cooler will result in the freezer operating at a temperature below the design value. Poor freezing conditions therefore often mean a low product loading and the air temperature will fall below the design value.

Fluidized and semi-fluidized freezers. One type of air blast freezer fluidizes the product with a strong blast of air from below (Fig. 25). The product then behaves like a fluid and when poured into the trough at one end, it moves along the length of the freezer without mechanical assistance and overflows at the exit. This type of freezer has been used successfully for such products as garden peas which are readily separated and kept apart but, as yet, the freezer has not had a wide application for fish or fishery products. Small cooked and shelled shrimp is one of the few fish products that has been successfully frozen by this method.

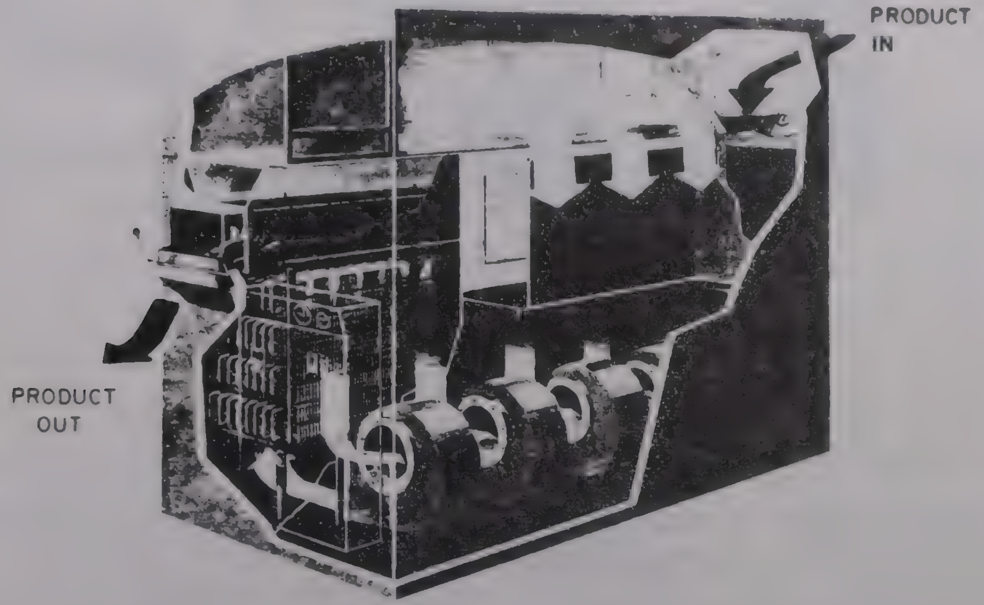

Fig. 25 A fluidized flow air blast freezer

A modified fluidized freezer which may be termed a semi-fluidized freezer has also been used for fish-freezing applications (Fig. 26). A conventional conveyor is used but at the early stages of freezing, sufficient air is blown from below the belt to agitate the product and ensure that individual portions remain separate until the outer surface has been hardened. This type of freezer can be used with a double belt, with transfer from one to the other midway through the freezing process.

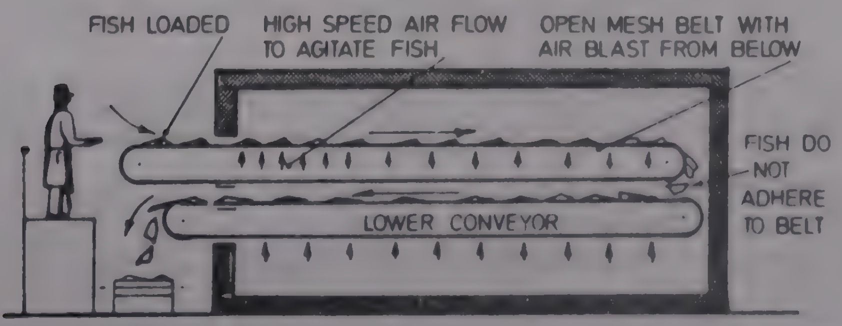

Fig. 26 Semi-fluidized flow freezer with double belt

There is however some difficulty in judging the correct air flow to produce the slight agitation required and a fixed flow rate is not suitable if a variety of products are to be frozen. Also, with many products there still remains some difficulty in making the transfer from one belt to the other.

Loading a batch air blast freezer. Because of their versatility, batch air blast freezers are often misused by operators who do not realize their freezing limitations.

The size of the refrigeration plant is fixed to match a given freezing requirement at the designed freezer operating condition. However, if the freezer is used for freezing different products which have different space requirements and freezing times, the freezer operating condition will change. Depending on the original design specification, the freezer may therefore be overloaded or underloaded by a change in product.

The examples shown in Table 3 show what happens when products of different freezing time are loaded in a batch freezer.

Table 3

Optimum loading of a batch air blast freezer

Product	Plant Capacity (t/h)	Load per freeze (t)	Freezing time (h)	Loading frequency	Freezing rate (t/h)
A	1	2	2	every 2 h	1
B	1	1	1	every h	1

In both examples in Table 3, the freezer is correctly loaded since the product load matches the plant capacity in the weight of fish that can be frozen in 1 h.

The above freezer would therefore be designed to hold 2 t of product A and when product B is frozen only 1 t will be loaded and the product distributed to given uniform air flow. If however, 2 t of product B are loaded into the freezer at one time, the refrigeration plant will be overloaded.

This is probably one of the most difficult aspects of freezer operation to explain clearly but in simple terms it means no matter how spacious your freezer is and how much product can be loaded, you cannot freeze more fish than the refrigeration plant will allow.

Good performance in batch air blast freezers is obtained by freezing the product in open trays without wrapping. Trays used in air blast freezers should transfer heat readily, be easily emptied and also be robust. Normally they are required to produce a pack that is of regular shape but the sides of the tray will require to be tapered slightly to assist the release of the frozen product.

When the product allows their use, trays with a taper on the sides of about one in eight can be emptied more easily by applying a cold water spray on the underside for a few seconds and then giving a gentle tap on the edge. Trays used in this manner should never be filled above the tray edge or the product will be damaged during release.

Cleaning and drying of trays before reuse is important to maintain a high standard of hygiene. Where the rate of production justifies the cost, an automatic tray washer may be installed.

Plate freezers. Plate freezers and air blast freezers are the types of freezer most commonly used for freezing fish in industrial countries. Plate freezers do not have the versatility of air blast freezers and can only be used to freeze regularly shaped blocks and packages.

Plate freezers can be arranged with the plates horizontal to form a series of shelves and, as the arrangement suggests, they are called horizontal plate freezers (HPF) (Fig. 27). When the plates are arranged in a vertical plane they form a series of bins and in this form they are called vertical plate freezers (VPF) (Fig. 28).

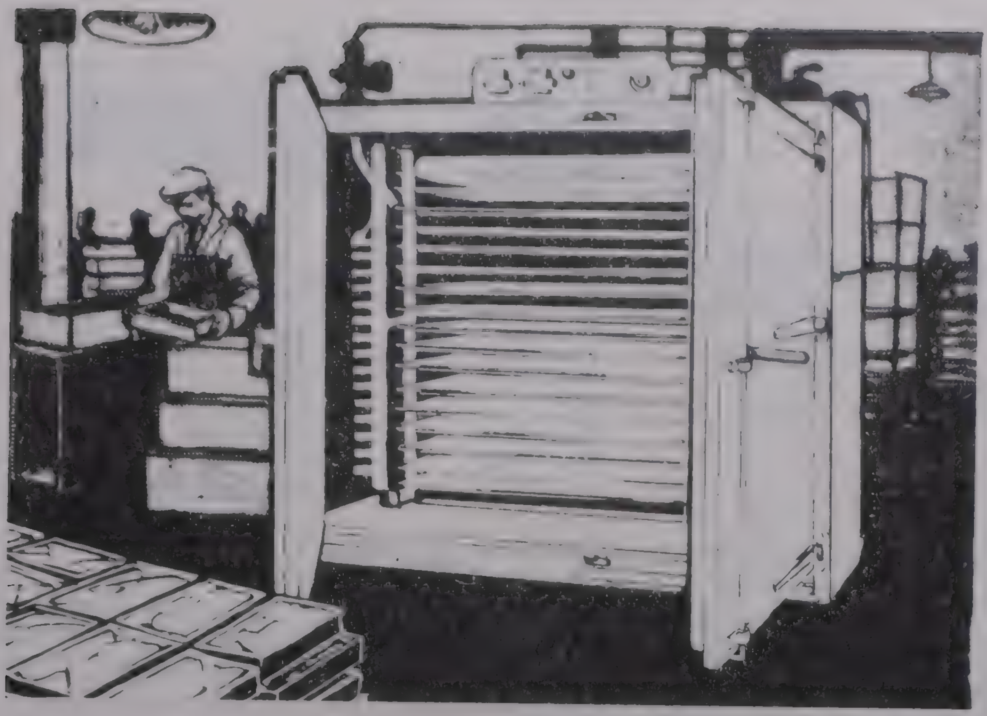

Fig. 27 Horizontal plate freezer

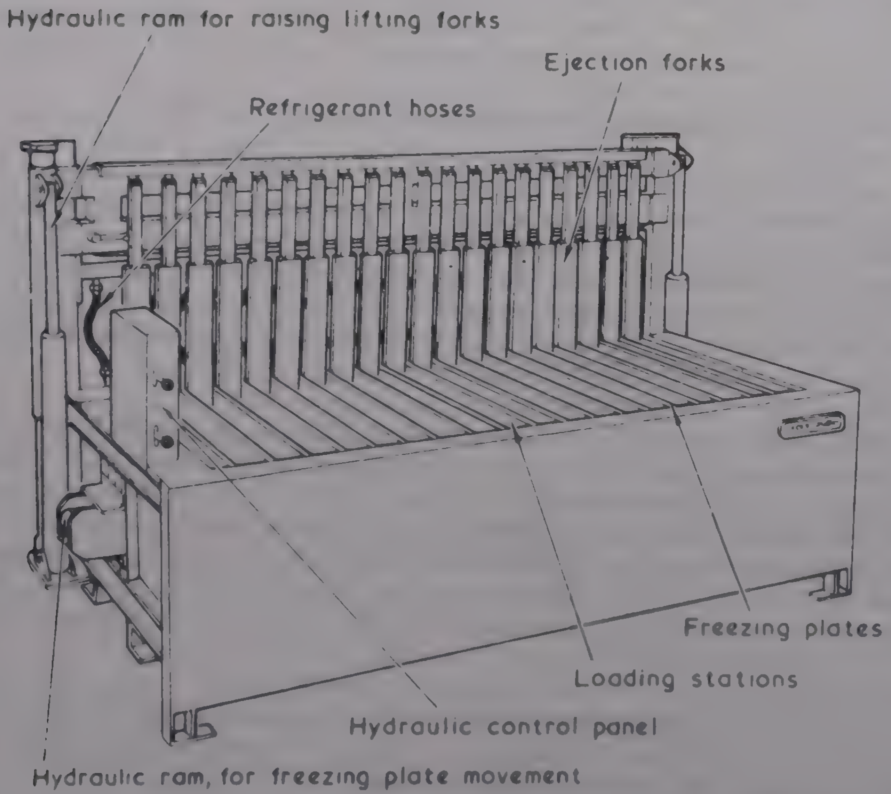

Fig. 28 Twenty-station vertical plate freezer with top unloading arrangement

Modern plate freezers have their plates constructed from extruded sections of aluminum alloy arranged in such a manner as to allow the refrigerant to flow through the plate and thus provide heat transfer surfaces on both sides. Earlier models of plate freezer used vacuum plates constructed with an internal pipe grid to contain the refrigerant and many of these are still in use. Heat transfer in these older plates was not good but later models were improved and these give results comparable with the aluminium plate (Fig. 29).

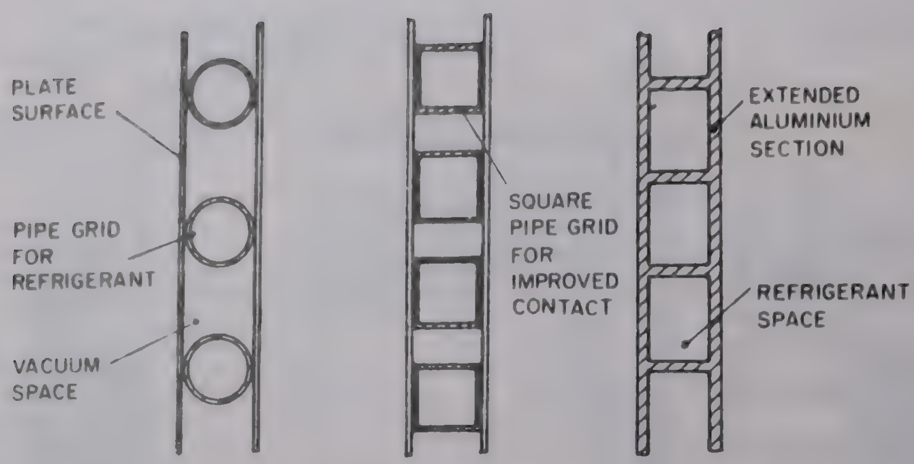

Fig. 29 Construction of plates used in contact plate freezers

All plate freezers are now fitted with hydraulic systems which move the plates to compact the produce and give higher density blocks. They also improve the fish-to-plate contact area for quicker freezing and assist with the release of the block after freezing.

Horizontal plate freezers. The two main uses for this type of freezer are the freezing of prepacked cartons of fish and fish products for retail sale and the formation of homogeneous rectangular blocks of fish fillets called laminated blocks for the preparation of fish portions. The thickness of package or block frozen is 32 to 100 mm and the freezer can readily adapt from the thicker to the thinner package provided the range required is made known to the supplier at the time of purchase.

Horizontal plate freezers need not be defrosted after each freeze.

There is no direct contact between the fish and the freezer plates when freezing by this method since the fish is always packaged before freezing. If the operator is also careful not to spill water on the plates during loading and unloading, the freezer may be operated with only a light brush between each freeze to remove surface frost, and a proper defrost may only be necessary once or twice per day. A hot gas defrost arrangement is the quickest method to defrost an HPF, but even with this method, it may take 30 min or more. The defrosted plate must be completely free from frost or ice and dried before the freezer is used again.

Horizontal plate freezers intended to be operated with a hot gas defrost are fitted with additional pipework which allows the cold refrigerant to be discharged from the bottom of the freezer as the defrost proceeds. Without this special pipework and operating valves, a hot defrost would clear the top plates only and leave the cold refrigerant in the plates at the lower levels. As in all hot gas defrost systems, the refrigeration system must have an adequate load to provide sufficient hot gas for an effective defrost. This system would therefore be better applied when there are two or more freezers operated from a common refrigeration system and each freezer will then be defrosted in turn while the others are in operation.

Horizontal plate freezers are often run without a defrost during the working day and the doors are left open overnight to allow the plates to defrost. This, however, is usually insufficient and water is hosed on the plates to assist the defrost procedure.

Defrosting is easier when a secondary refrigerant is used or when the freezer operates with a pump circulated primary refrigerant. With these systems, a reservoir of warm liquid can be made available for pumping through the plates.

An HPF will only operate correctly if good contact is made on both the top and bottom surfaces of the pack or tray to be frozen. The faults shown in Fig. 30 are some of those which make freezing times longer than necessary. If the product is frozen from one side only due to poor contact on the upper surface, the freezing time could be three or four times as long as the time achieved with good contact on upper and lower surfaces. The plates of the HPF are closed by means of a hydraulically operated piston to make contact with the upper surface of the product. The pressure applied can readily be varied to suit the product but 0.5 kg/m^2 is common and is increased by a factor of two as the fish expands during freezing.

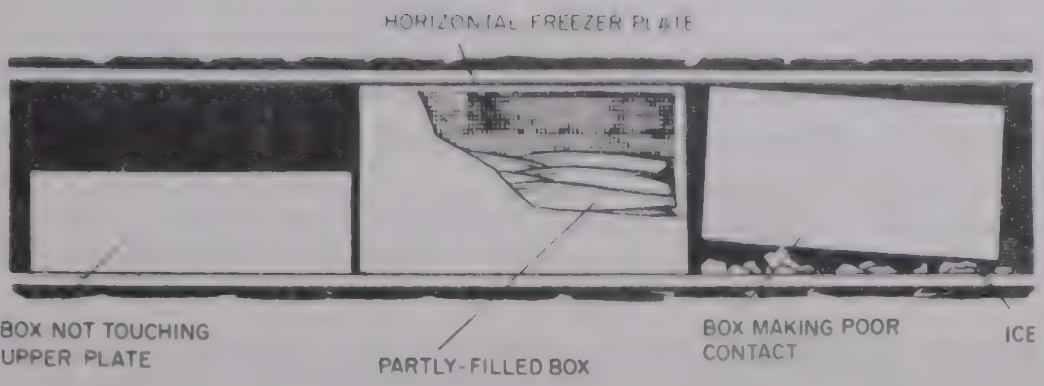

Fig. 30 Some reasons for poor performance in a horizontal plate freezer

Vertical plate freezers. The main advantage of using this type of freezer is that fish can be frozen in bulk without any previous requirement to package or arrange on trays. The plates form what is in effect a bin with an open top and fish are loaded directly into this space. This type of freezer is therefore particularly suitable for bulk freezing and it has also been extensively used for freezing whole fish at sea. The maximum size of block made by this method is usually 1 070 mm x 535 mm. Other dimensions of block, however, can be produced and block thickness can vary from 25 to 130 mm. The block dimensions selected will depend on the fish to be frozen and also the maximum block weight that can be readily handled by the operators. Maximum block dimensions and weight are limited by the physical effort required from the operator to lift the block, and by the ease with which he can handle the block so that damage to the fish is kept to a minimum.

In most cases, fish can be loaded between the plates without wrappers and water need not be added either to strengthen the frozen block or improve the contact with the plates. Fish such as cod and haddock produce compact blocks with a block density of approximately 800 kg/m^3.

With fatty fish such as herring, it has been found advantageous to use wrappers and add some water to fill the voids in the block. Fatty fish do not form blocks which are as firm and strong as blocks made from lean fish especially during seasons when the oil content of the fish is high. Water added to the block helps to strengthen the block, protects the fish during subsequent handling and reduces the effects of dehydration and oxidation during cold storage. Well formed, rigid blocks are particularly important when freezing at sea. The frozen product is handled under particularly adverse operating conditions and poorly formed blocks would result in a high percentage of broken blocks and loose fish. Machine filleting or splitting of the fish, for instance, may be difficult if fins and tails are broken. Wrappers have therefore been used when freezing fatty fish in VPF to protect the exposed fish on the outside of the block. A wrapper that has been found suitable for this purpose is a single layer paper bag, coated internally with polyethylene, and shaped to fit the space between the freezer plates. Wrappers made from polyethylene and other plastic materials were found to be difficult to handle and constituted a danger when stacked due to slipping.

Fish frozen with wrappers will inevitably require a longer freezing time due to the insulating properties of the wrapping material. Some types of wrapper would have a considerable effect on freezing time but the material described did not increase the freezing time by a significant amount.

Vertical plate freezers are defrosted to release the blocks of fish after each freeze. Fish in VPF are in direct contact with the plates and the force required to release the blocks without a defrost would be excessive and result in plate damage. The defrost time for a VPF need not exceed 3 or 4 min if a suitable supply of defrost gas or hot liquid is available. If a primary refrigerant is used in the plates, a hot gas defrost is generally used and when there is a multiple freezer installation, the freezers are defrosted in turn with the other freezers in operation providing the necessary refrigeration load for the compressor. When a secondary refrigerant is used, a reservoir of hot liquid has to be maintained and pumped through the plates to displace the cold liquid present. With this arrangement, it is possible to return the bulk of the cold liquid to the low temperature reservoir at the start of defrost, and also return the warm defrost liquid to the hot liquid reservoir for reheating at the start of the next freeze. This arrangement reduces the quantity of liquid interchanged at each defrost but even with this system provision must be made to maintain the liquid charges in both the cold and hot systems at the correct level.

A defrost arrangement such as those described above means that the refrigeration pipework is a good deal more complicated and expensive to install. Attempts have been made to assist the release of the blocks by coating the plates with a low friction plastic material so that a defrost was unnecessary. Although this worked reasonably well, a defrost was found to be essential for another purpose. When fish are loaded between plates at a temperature below 0°C, they stick to the plates and do not settle down to form a compact block. The result is that freezing times are longer due to the poor contact being made with the plates and, because of the lower block density, more storage space is required for a given quantity of fish. The results of some tests that clearly show this difference in loading fish between warm plates and plates at refrigerated temperatures are given in Table 5. The first two results in the table were obtained when the fish were loaded between defrosted plates. The last results, which gave low density blocks and longer freezing times, were obtained when fish were loaded between cold plates.

Vertical plate freezers can be made with top, side or bottom unloading of the blocks. Generally, top unloading models are preferred since the block is lifted clear of the plates and presented at a suitable height for handling by the freezer operator.

Vertical plate freezers may be supplied in units with up to 30 stations and some thought has to be given to the selection of the correct unit size for each particular requirement. An installation may consist of a number of freezer units which are loaded in rotation. If 12 units are used, and the freezing cycle takes 4 h, 1 unit will be defrosted, unloaded and reloaded every 20 min. If this frequency of operation fits in with a suitable work rate and the fish can be handled in and out of the freezers in this time, then the 12 units are suitable for this particular application. Individual units should not be partially loaded, freezing commenced and the rest of the unit loaded later. A further defrost would be necessary and this would reheat the partially frozen fish. The freezer unit size should therefore be matched to the rate at which fish becomes available for freezing. This will ensure that fish are not kept waiting for the unit to be fully loaded and that the freezers are not operated with partial loads for a good deal of the time. If, however, the fish supply rate and the freezer capacity are not matched, it is better to freeze a partial load of fish rather than wait for a full load. Fish can deteriorate quickly at this stage of processing, particularly if it is not chilled and also remains ungutted.

The following are brief descriptions of a variety of freezers that have been used for freezing fish but have not as yet been widely adopted either because they are new developments or because they are special purpose equipment with only a limited application.

Automatic plate freezers. This type of freezer freezes fish in cartons and is a continuous form of the HPF. Automatic plate freezers are specially designed for a processing line; and units with capacities of up to 2 t/h are available. Their main advantage is that they save the labour required for the loading and unloading of batch plate freezers. However, when this labour saving is related to the total labour requirement for packing and other operations, the saving is often not significant.

Drum freezer. This is a novel type of continuous contact freezer which has recently been reintroduced and which is suitable for a variety of IQF products. The freezer is a rotating drum with pump circulation of a secondary refrigerant used to cool the internal surfaces. The product is placed on the drum and if the product surface is wet, it immediately adheres to the surface of the drum. The drum speed is regulated to give the appropriate freezing time for each product and on completion of one revolution, the frozen product is dislodged by a scraper. The drum curvature will impose its shape on the product to be frozen but with shrimp this is not noticeable, and with fish fillets there is only a slight distortion if the fillets are placed so that they lie parallel to the drum axis.

This type of freezer is compact and may well prove useful for IQF fish products since the smooth surface of the drum and absence of a cooler that requires defrosting eliminates some of the problems encountered in a conventional continuous air blast freezer. Its use will however be confined to products that can be frozen fairly rapidly and also to those that adhere to the drum surface. With some products, there will also be difficulty in removing them from the frozen surface.

Continuous freezer with brine cooling. A continuous freezer with much the same layout as a continuous air blast freezer uses a refrigerated brine to cool a conveyor belt made from stainless steel sheet. The product to be frozen is placed on the upper surface of the belt and, as it is conveyed through the freezer, a refrigerated brine is sprayed onto or pumped across the lower surface. With the pump circulated method, the belt virtually floats on a layer of cold brine. Freezing times will be longer than with an HPF since freezing is from one side only but this can be reduced by incorporating a conventional air blast freezer system to cool the upper surfaces. Freezing times when using the brine only will be comparable with an air blast freezer if the product is in the form of thin pieces. For thicker products, freezing times will be comparatively long.

Like the drum freezer, this type of freezer overcomes some of the main problems encountered with continuous air blast freezers such as the need to defrost cooler surfaces. The plain stainless conveyor belt used also makes it easy to keep clean, and the fish are readily removed after freezing. This type of freezer has not as yet been widely used for freezing fish products.

Liquid nitrogen freezer. In this freezer, the product is brought into direct contact with the refrigerant (Fig. 31).

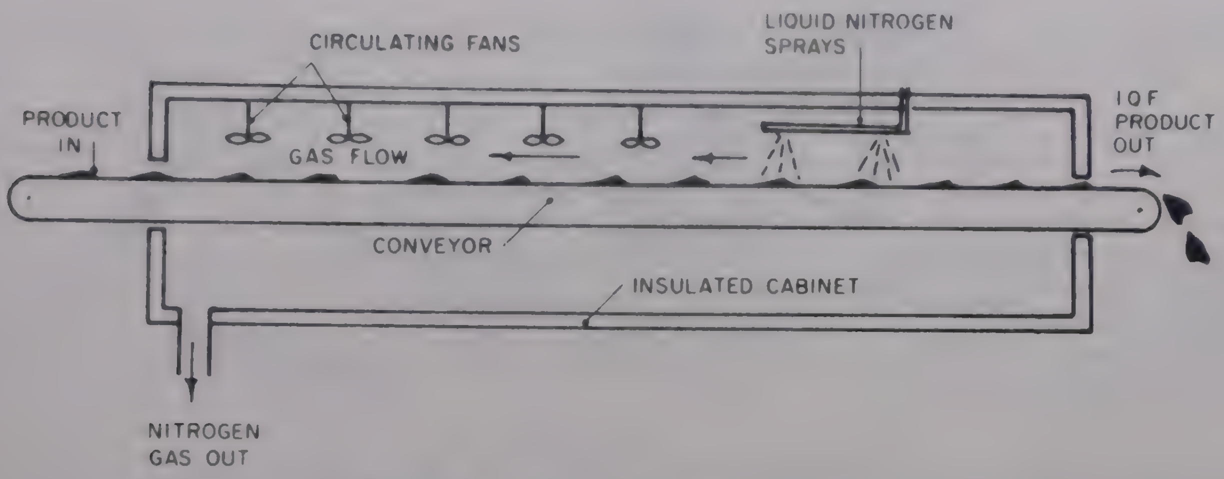

Fig. 31 Liquid nitrogen freezer

The fish on the stainless steel conveyor belt initially come into contact with the countercurrent flow of nitrogen gas at a temperature of about -50°C. As the fish progress through the freezer, the temperature of the cooling gas progressively falls to -196°C. This initial stage of cooling in the gaseous nitrogen partially freezes the fish and also preconditions the product before it is passed below the liquid spray where freezing is completed by the boiling liquid. During this precooling stage, up to 50 percent of the product heat is extracted and the remainder of the heat transfer takes place in the small area below the sprays. After leaving the spray zone, the last stage in the freezer is used for the fish temperature to reach equilibrium before the fish are discharged.

If fish are cooled directly below the sprays without preconditioning, they are physically damaged due to the sudden change in temperature which sets up thermal stresses within the fish.

The main advantage of the nitrogen freezer is that freezing is very quick and the physical size of the freezer is correspondingly small. The freezer is operated without the need for compressors, condensers or coolers; therefore maintainance requirements are minimal and the power required to operate the freezer is very low. Liquid nitrogen cannot be retained economically in a pressure vessel and continuous venting is required to keep the contents cool and the internal pressure down. One estimate given is that 0.5 percent of the stored contents is lost each day by this method. In addition, about 10 percent has been estimated to be lost during the transfer of liquid from the tanker to the storage vessel although the customer is not charged directly for this loss. This method of freezing is more expensive than most others, being at least four times more costly than conventional air blast freezing, or even higher if the freezer is only used intermittently with partial loads.

Although the freezer is small and there is no refrigeration machinery requirement, storage space and access is required for the liquid nitrogen tank.

The main disadvantage of this type of freezer in most developing countries is that delivery of nitrogen would be expensive and there may be no guarantee of regular supplies.

Liquid freezant freezer. The liquid freezant freezer (LFF) uses a specially purified form of dichlorodifluoromethane (R12) which has a boiling point of -30°C at normal atmospheric pressure (Fig. 32).

Two methods of operation are employed depending on the product being frozen. In the first method, the loading conveyor drops the product into a tank of freezant and, due to the good heat transfer, the surface is frozen almost instantaneously. This enables the product to remain as separate units during the rest of the freezing process. After this initial immersion, the product is transferred to a

horizontal belt, and freezing is completed by spraying with more refrigerant. A discharge conveyor finally lifts the product out of the freezer. On contact with the product the refrigerant evaporates and the vapour formed is recovered by condensation on the surface of a heat exchanger. The heat exchanger used for this purpose is the cooler of a conventional refrigeration system.

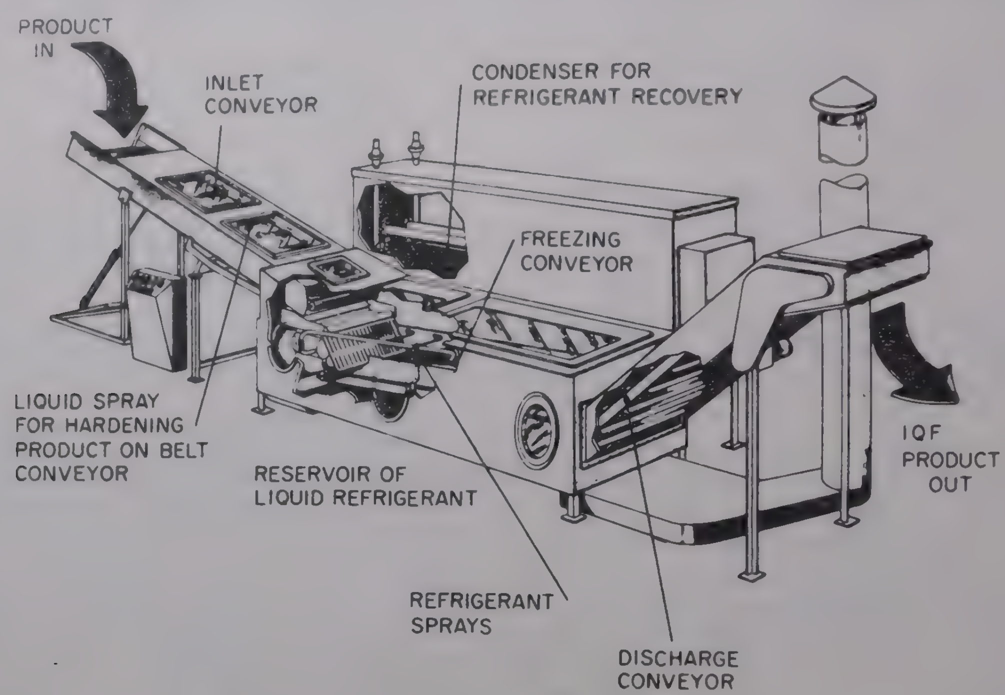

Fig. 32 Liquid freezant freezer

The second method of operation is the one likely to be used for most fish products. In this method, the fish are sprayed with refrigerant while they are on the feed belt. This process sufficiently hardens the fish so that when they are dropped into the tank of refrigerant, they retain their shape.

Freezing by direct contact between R12 and the fish has not yet been approved in some countries since there is some concern about the retention of the refrigerant in the frozen product. However, where the method has been allowed, it has proved useful for many IQF products. Freezing times are comparable with those attained in nitrogen freezers but the cost of freezing is a good deal less being about half the cost of nitrogen freezing and therefore about double the cost of conventional air blast freezing.

Although the refrigerant is recovered, there are small losses, and equipment manufacturers claim these to be between 1 and 3 percent. This loss may sound small, but in a large installation, a good deal of refrigerant is required for make-up, and again the operator would require to be guaranteed regular supplies.

Unlike liquid nitrogen and carbon dioxide freezers, the LFF has a conventional refrigeration system for refrigerant recovery and all the usual requirements for the operation and maintenance of this type of unit are necessary.

Carbon dioxide freezer. This type of freezer has been known for a long time and uses carbon dioxide which is usually a by-product of another industrial process. Recent attempts have been made to reintroduce freezers using liquefied carbon dioxide as a refrigerant, and batch and continuous models are now available.

The liquefied carbon dioxide is injected into the freezer and comes into direct contact with the product. In this respect, it is similar in operation to an LNF. With large units, it is economically feasible to recover the carbon dioxide and about 80 percent of the refrigerant used can be reliquefied and recirculated.

Carbon dioxide can be contained in vessels at a moderate pressure and losses during storage are therefore negligible.

High levels of carbon dioxide in the factory air are dangerous, therefore, a freezer using this refrigerant must be vented and the gas discharged outside the building.

Again as is the case with other types of freezer which rely on regular supplies of refrigerant, carbon dioxide freezers would not be suitable for use in remote areas.

Immersion freezers. By using a liquid for the transport of heat from a product, favourable freesing rates can be achieved. A liquid can transport more heat per unit volume than air but, like air, a stagnant boundary layer is formed which slows the transfer of the heat. Liquids used for heat transfer must therefore be circulated over the product. Unlike air, difficulties due to high viscosity often arise when a liquid is used at a low temperature. The lower the temperature, the higher the viscosity, therefore, this factor often limits the use of some liquids.

Many other liquids that have suitable refrigeration and heat transfer properties are not allowed to be used in direct contact with food. Many of the liquids that are used are limited in their use because they cause changes in texture and taste in the food with which they are in direct contact.

Immersion in sodium chloride brine was one of the very first methods used to freeze fish since it was a logical progression from the method used to freeze block ice.

Brine immersion freezing is still used for such fish as tuna which are intended to be marketed as a canned product. The fish are large and have a thick skin; therefore the uptake of salt is not great. The little salt that is absorbed is not detrimental to the canned product since salt is usually added to the product before canning in any case. For many other fish freezing applications, adverse effects on texture and taste of the fish due to the absorption of brine have proved to be unacceptable. Even without excessive brine uptake, the surface of the fish will be coated and handling the product after freezing is difficult and messy.

The most effective brine freezing technique is the use of a eutectic solution of common salt which contains about 22.4 percent salt and the remainder water, and which can be maintained at a temperature of $-21^{\circ}C$. In order to obtain a reasonable rate of heat transfer, the brine requires to be circulated. However, too much agitation will damage the fish and therefore a compromise has to be made. An average brine velocity of about 0.2 m/s is often used and the circulation system should be arranged to ensure that there are no stagnant areas within the brine tank.

In order to avoid a large fluctuation in temperature when the fish is added, the mass of brine must be far greater than the mass of fish. A ratio of at least 50 to 1 has been quoted as necessary for an even temperature to be maintained. The size of the cooling coil is also large since it is undesirable to have too great a temperature difference between the coil and the bulk of the brine. A temperature difference of about 1 degC has been quoted and a rule of thumb method dictates that the cooling coil area should be about 20 times the total surface area of the fish being frozen.

It can be seen from the above description that brine freezing requires a rather large tank, that it is a messy process and corrosion is an ever present problem. These disadvantages together with the effect on the product have made brine freezing unattractive and the method is gradually being phased out. Finally, sodium chloride brine does not allow the fish to be frozen down to a storage temperature of $-30^{\circ}C$. Thus if the method is used to freeze fish for storage at this temperature, there is a high cold store product loading.

Some fish products such as shrimp have been frozen in syrup and salt solutions, and sugar and salt solutions but again there is some degree of absorption with changes in flavour.

Other types of freezer. The reader will no doubt find other types of freezer are available on the market but which have not been mentioned. The design of many of these is based on combinations of two or more of the basic methods described. For instance, a variety of freezers make use of both contact and air blast freezing techniques. Other freezers may be identical in every respect with one of the methods described, but may use some other liquid gas or contact method for heat transfer. These freezers will readily be seen to be similar to one of the types described and will therefore have the same advantages and disadvantages.

One type of hybrid freezer requires special mention since it is still widely used. The sharp freezer (Fig. 33), is one of the oldest types of freezer used for food and although its design is based on good principles, it does not always perform well in practice.

A sharp freezer usually consists of a room with cooling pipes arranged as shelves, one on top of the other with a shelf spacing of about 25 cm. The refrigerant is circulated within the pipes and the product is either placed directly on the shelf if it is a large fish or package, or loaded into trays or pans. The air in the room is agitated by fans located at roof level and usually above the central passageway.

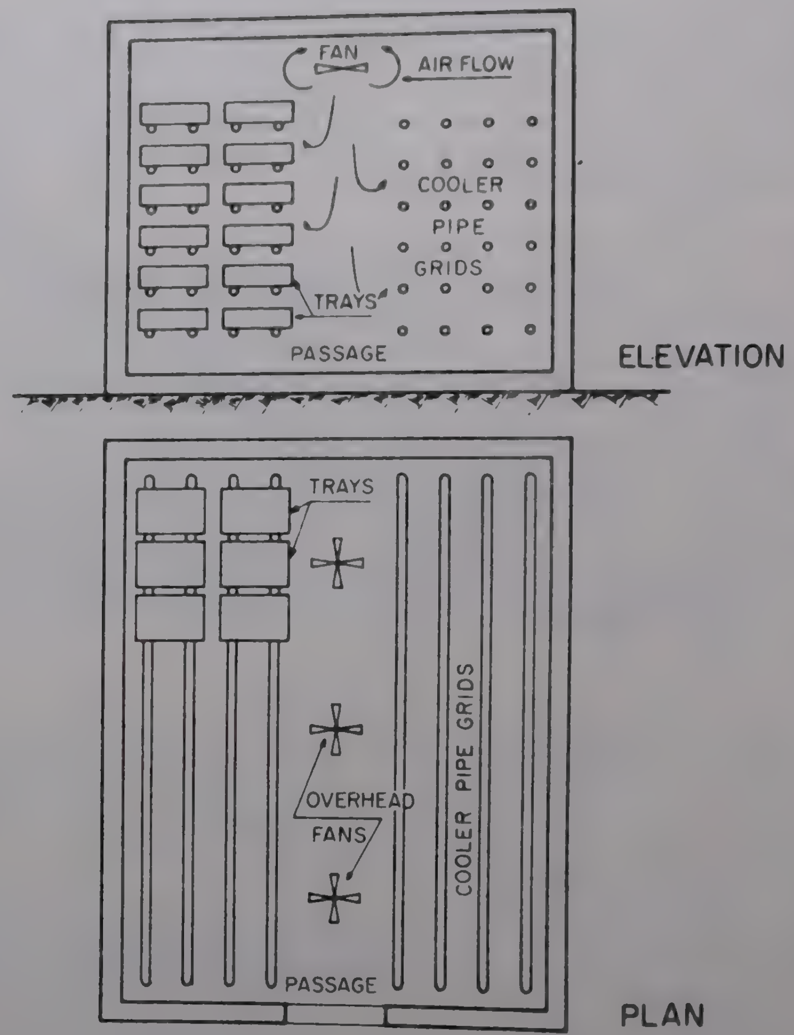

Fig. 33 Sharp freezer

No attempt is usually made to direct the air uniformly over the surface of all fish in the freezer; therefore transfer of heat by this method is unpredictable and irregular. Contact with the refrigerated coils is made only over a small area and the pipes are usually well covered with frost and ice.

Sharp freezers are often rather large units and, because the product has to be placed on fixed refrigerated shelves, loading aids such as pallets and trolleys cannot be used. The time taken to load the freezer is therefore long and may in some cases extend to a number of hours. Freezing is usually accomplished overnight with a freezing time of 12 to 15 h and the equally laborious unloading procedure is started in the morning. This means that fish being loaded into a vehicle for transport to a store are often exposed to ambient conditions for long periods. If the fish are transferred directly to an adjacent cold store again, the methods used mean that the cold store door is left open for long periods.

Sharp freezers are still extensively used in some countries but they are gradually being phased out. The sharp freezer does not fit well into modern fish processing arrangements and the freezing times achieved often do not conform with recommended practice. Where they are likely to be used for some time, attempts should be made to streamline the loading and unloading procedures and often minor modifications can improve the distribution of air flow over the product.

Freezer operating temperatures

Bearing in mind that the freezer must reduce the temperature of the product to the intended temperatures of storage, freezers should operate at temperatures which allow this to be accomplished under the most favourable economic conditions. When selecting the appropriate freezer operating temperatures, account should also be taken of cost of equipment, operating costs, space requirements, quality considerations and other factors. In some types of freezer, the temperature is fixed by the nature of their

method of operation, whereas in others such as air blast and plate freezers, there is scope for varying the temperature to suit any particular requirement.

The following table gives some typical operating temperatures for various freezers:

Table 4

Freezer operating temperature

Type of freezer	Operating temperature (°C)
Batch air blast	-35 to -37 air
Continuous air blast	-35 to -40 air
Batch plate	-40 refrigerant
Continuous plate	-40 refrigerant
Liquid nitrogen	-50 to -196 refrigerant
Liquid carbon dioxide	-50 to -70
Liquid freon freezant	-30 freon, -40 condenser
Sodium chloride brine	-21 refrigerant
Drum	-45 refrigerant

Space requirements for freezing

The space required for a freezer obviously depends on capacity and also on the type of freezer. To cover all eventualities would therefore involve the production of long lists to cover all capacity ranges for the multitude of freezers available. Since this is not practical, only a brief mention will be made of what must be taken into account when calculating the total freezer space required.

It can generally be assumed that for a given capacity requirement, the quicker a freezer can freeze the product the smaller will be the physical space required for the freezer unit. Freezer space, however, is only one factor to be taken into account when calculating the total space requirement. The following additional space requirements must also be considered. Some distinction, however, should be made between floor space required within a building and the space required in an open yard outside the covered factory area. Space is required for refrigeration machinery for most freezers but for small units, the machinery may be located above or below the freezer unit and will not add to the floor space requirement. With liquid nitrogen and carbon dioxide freezers, no mechanical refrigeration is required, but storage space must be made available for the refrigerant. In addition, space has to be made available for manoeuvring the tanker supplying the refrigerant.

A working area is also required for preparing the product for freezing. If the fish has to be packaged before freezing, this space has to be added to the freezing requirement. Trolleys and pallets also require space and if they are doubled up to allow for a rotation system to be used, the floor space occupied by this equipment can be considerable.

Loading and unloading the freezer and access for control or maintainance may also increase the floor space requirement.

Space is also required to release fish from trays and an area is required to wash, dry and store these trays.

Packaged products also require space for storing the packaging material. This material is often printed or marked to identify the product and the company, and this requirement often means ordering in large quantities.

Total space can therefore be far in excess of the actual freezer space and comparisons made on the basis of this total requirement are often completely different from those made when the freezer unit only is considered.

Labour requirement for freezing

Low labour requirements for loading and unloading freezers are often quoted by manufacturers to impress potential customers. These labour requirements, however, can be misleading. Freezers which freeze packaged fish products without the need for physically handling the fish in and out of the freezer unit can rightly be said to require the minimum of labour to operate the freezer. Much of the labour requirement, however, has merely been transferred to another part of the process. Labour requirements should therefore be assessed as a whole and savings in the freezer labour requirement may only be identified by studying what has to be done before, during and after freezing.

Few fish products when dumped on a conveyor belt can sort themselves out and be loaded into a freezer. Claims for freezers that can be operated in this way are usually based on experiences gained with other food products, such as fruit and vegetables.

Calculation of freezer refrigeration load

The individual items to be taken into account in a refrigeration load calculation depend on the type of freezer. It would be impossible to include all the eventualities in one sample calculation; therefore, a relatively simple one is given below for a VPF and some notes have been added to help with other freezer calculations.

Specification

100 mm thick blocks of fish each weighing 45 kg
Capacity (32.4 t/day)
Secondary refrigerant temperature (-40°C)
Evaporating temperature (-47°C)
Fish initial temperature (10°C)
Cycle time (4 h)

Load calculation

I. Number of freezers

32.4 t/day = 32 400 kg/day

$\frac{32\ 400}{45}$ = 720 blocks/day

$\frac{24}{4}$ = 6 cycles/day

$\frac{720}{6}$ = 120 blocks/cycle

II. Fish load

$\frac{32\ 400}{24}$ = 1 350 kg/h

Enthalpy at 10°C = 85.9 kcal/kg

Enthalpy at -30°C = 4.6 kcal/kg

Change in enthalpy = 81.3 kcal/kg

Heat to be removed = 1 350 x 81.3 = <u>109 755</u> kcal/h

The change in enthalpy value (the heat to be removed from the fish during freezing) used in the calculation is obtained from Table 19 or Fig. 56 and this is a true measured value for cod. An approximate figure can also be calculated by using the following values:

(a) Specific heat of fish above freezing, 0.9 kcal/kg°C

(b) Latent heat of the fish, 60 kcal/kg

(c) Specific heat of fish below 0°C, 0.4 kcal/kg°C

Using these values, the above calculation for fish refrigeration load would be:

Heat to remove on cooling to 0°C, 1 350 x 0.9 x 10	=	12 150 kcal/h
Latent heat to remove, 1 350 x 60	=	81 000 kcal/h
Heat to remove on cooling to -30°C, 1 350 x 0.4 x 30	=	16 200 kcal/h
Total heat to remove from fish	,	109 350 kcal/h

Total refrigeration requirement with allowances:

Method I - Add 30% = 109 755 x 1.3 = 142 681 kcal/h

Method II - Assume 18 h/day running

$$109\ 755 \times \frac{24}{18} = 146\ 340 \text{ kcal/h}$$

These methods give nearly the same allowance and both calculations are only used here to show the reader how these refrigeration allowances can be applied by different designers.

In the above example, it is the freezing cycle time that is used in the calculation, not the actual freezing time of the block of fish. Account has therefore been taken of the time it takes to load and unload the fish and any minor delays. This time is therefore more realistic when calculating freezer size.

The calculation of fish load gives the refrigeration requirement to freeze the fish only. Depending on the type of freezer used, other heat loads have to be taken into account and added to this value to determine the total refrigeration requirement. Some of these additional heat loads are:

Fan heat
Pump heat from circulating pump
Heat leak through freezer insulation
Heat load due to pallets, trays, trolleys, etc.
Heat load due to a defrost procedure
Heat load due to air infiltration
Heat load due to internal lighting

Once the total load has been calculated, a factor is added which will take care of peak loading, small loads unaccounted for and eventual deterioration of the freezer and refrigeration equipment. There are no fixed rules for applying this operating factor since it will vary with the equipment and type of operation. Only experience can be used to make a fair judgement but, if no expert guidance is available, applying the factor of only 18 h running time in every 24 h, shown in the calculation, should make adequate provision in most cases.

A generous allowance for refrigeration machinery for freezers need not, in the end, be an expensive addition. Even short delays due to plant breakdown or reduced performance of equipment can be expensive, especially when freezing at sea.

Ordering freezers

Buyers specification. The buyer should supply in writing all the information he has about the products, the proposed freezer, the site and facilities available. The more facts the buyer gives, the easier it will be for the contractors to submit tenders that the buyer can compare on a common basis.

Ideally, the buyer should provide as much of the following information as possible when ordering a blast freezer:

The kinds of fish product to be frozen
The shape, size and packing of each product
The freezing time of each product
The product initial temperature
The intended cold storage temperature
Required daily output for each product in metric tons or kilogrammes
Normal freezer working day in hours

The average air temperature required in the freezer section
The average design air speed required in the freezer section
Type of air blast freezer required with sketch plan
The position of freezer in factory premises with a sketch plan showing its location in relation to other parts of the process
Maximum headroom available at the freezer location
Availability and specification of present electricity and water supplies
Reliability of electric supply and quality of water
Maximum ambient temperature
Spare parts required
Availability of maintenance facilities and skilled labour for plant operation

The above list is by no means exhaustive and may be added to; for instance, reference should be made to any local laws that may affect the siting or operation of the freezer. Most of the information above will require to be supplied for other types of freezer together with additional information that may be considered relevant.

No detail is too small to assist the supplier to provide the exact equipment to meet the buyer's requirements.

The contractor should also supply a complete written specification of the equipment being offered and also a detailed sketch plan showing the layout and space requirements of the freezer refrigeration plant and other ancillary equipment.

The following notes and lists will give some guidance on what information may be supplied so that the customer is quite clear about all details of the plant being offered.

Refrigeration capacity is sometimes quoted in terms of the power of the condensing unit's electric motor. There is such a loose relationship between them that motor power is at best only a very rough guide. Refrigeration capacity is sometimes quoted in terms of kcal/day or quantity of fish frozen per day without specifying what is meant by a day; is it 24 h or is it a working day of 8 h? In order to avoid confusion, capacity should be quoted as an hourly rate in kcal/h and it should be made clear whether this is the gross capacity of the condensing unit for all duties or the net heat extraction rate available for freezing the fish only. If there is likely to be confusion, both the gross and net values should be given.

Another common error is to ignore the intended operating conditions when quoting the refrigeration capacity. It is important that compressor capacities should not be quoted at standard rating conditions or any other unrelated condition. The following additional information should also be specified by the contractor:

Refrigeration machinery:

Number and type of compressors
Compressor operating conditions
Total refrigeration capacity
Refrigeration capacity of each compressor in kilocalories per hour at design condition
Power of compressor motors in Watts or kiloWatts
Maximum electrical power requirement in Watts or kiloWatts
Compressor safety arrangements
Condensers, number and type
Water consumption in cubic metres per hour
Circulating pumps for condenser
Fan power requirements for condenser
Sketch of machinery layout showing total space required

Refrigeration system:

Refrigerant used
Type of system
Initial refrigerant charge in kilogrammes
Power of circulating pumps for refrigerant
Standby arrangements, if any
Method of temperature control, if any
Temperature control limits

Freezer:

Sketch of freezer layout showing total space requirement
Weight of load for each product specified
Output in metric tons per hour or kilogrammes per hour for each product specified
Output in metric tons or kilogrammes for normal working day including allowance for loading
Recommended loading procedure
Air temperature in freezing section
Number and capacity of fans
Air speed in empty freezer in metres per second
Air speed over the product in metres per second
Air temperature rise over the product
Method of defrosting
Instrumentation supplied
Type of insulation
Thickness of insulation in millimetres
Method of erection of insulation
Type of vapour sealing
External finish
Internal finish
Door arrangement
Door heaters
Frost heave precaution, if any
Lights

3. FREEZING TIME

The freezing time is the time taken to lower the temperature of the product from its initial temperature to a given temperature at its thermal centre. Most freezing codes of practice require that the average or equilibrium temperature of the fish be reduced in the freezer to the intended storage temperature. The final temperature at the thermal centre is therefore selected to ensure that the average fish temperature has been reduced to this storage value.

The recommended storage temperature for frozen fish in the U.K. is -30°C and, to ensure that the fish are frozen quickly, the temperature of the freezer must be lower than this.

The surface of the fish in a freezer will be quickly reduced to near the freezer temperature. Thus when the warmest part at the thermal centre is reduced to -20°C, the average temperature of the fish will be close to the required storage temperature of -30°C. The freezing time, in this particular case, will therefore be defined as the time taken for the warmest part of the fish, at the thermal centre, to be reduced to -20°C.

Variables which affect freezing time

Freezer type
Freezer operating temperature
Refrigeration system and operating condition
Air speed in an air blast freezer
Product temperature
Product thickness
Product shape
Product contact area and density
Product packaging
Species of fish

The above factors will determine the overall heat transfer coefficient and hence the freezing time.

Freezer type. The type of freezer will greatly influence the freezing time. For example, due to a better surface heat transfer coefficient, a product will normally freeze faster in an immersion freezer than in an air blast freezer operating at the same temperature.

Operating temperature. The colder the freezer, the faster the fish will freeze. However, the cost of freezing increases when the freezer temperature is reduced, and in practice, most freezers are designed to operate only a few degrees below the required storage temperature of the product. For example, plate

freezers usually operate at about -40°C and blast freezers at about -35°C when the storage temperature is -30°C.

Air speed in blast freezers. The general relationship between air speed and freezing time is shown in Fig. 4 and this shows that freezing time is reduced as the air speed is increased. This, however, is a rather complicated relationship and it depends on a number of factors. If the resistance to heat transfer of the stagnant boundary layer of air is important, changes in air speed will make a significant difference to the freezing time. If, however, the package is large and the resistance of the fish itself is the important factor then changes in air speed will be less significant. Air temperature, air density, air humidity and air turbulence are other factors that have to be taken into account when the effect of air condition on freezing time is considered. Some of these factors however, may only have a minor effect

Product temperature before freezing. The warmer the product, the longer it will take to freeze. Fish should therefore be kept chilled before freezing both to maintain quality and reduce freezing time and refrigeration requirement. For example, a single tuna 150 mm in diameter frozen in an air blast freezer will take 7 h to freeze when the initial temperature is 35°C but, only 5 h when the temperature is 5°C.

The initial temperature of the product should therefore be given when quoting a freezing time.

Product thickness. The thicker the product, the longer is the freezing time. For products less than 50 mm thick, doubling the thickness may more than double the freezing time whereas doubling a thickness of 100 mm or more may increase the freezing time fourfold. The rate of change of freezing time with thickness therefore, depends on the relative importance of the resistance of the fish to heat transfer.

Product shape. In a freezer suitable for freezing single fish, a round fish will freeze in about two thirds of the time taken for a flat fish of the same thickness. The shape of a fish or package has therefore a considerable effect on its freezing time.

Product contact area and density. In a plate freezer, poor contact between product and plate results in increased freezing time. Poor contact may be due to ice on the plates, packs of unequal thickness, partially filled packs or voids at the surface of the block. Surface voids are often accompanied by internal voids and this also results in poor heat transfer. Apart from increasing freezing time, internal voids also reduce the density of the block. The relationship between time, block density and contact area for 100 mm blocks of white fish is shown in Table 5.

Table 5

Variation of freezing time with density and contact area

Block density (kg/m^3)	Contact area (%)	Freezing time (h)
800	48	3.0
780	45	3.0
650	29	3.8
650	21	4.0

Product packaging. The method of wrapping and the type and thickness of the wrapping material can greatly influence the freezing time of a product. Air trapped between wrapper and product has often a greater influence on the freezing time than the resistance of the wrapping material itself. The following example illustrates the point. Smoked fish in a wooden box with the lid on take 15 h to freeze in an air blast freezer. Smoked fish in an aluminium box of the same shape and size and with the lid on take 12 h, but if the lid is taken off the wooden box, the freezing time is only 8 h because there is no trapped air acting as an insulation.

Species of fish. The higher the oil content of a fish the lower is the water content. Most of the heat extracted during freezing is to change the water to ice; therefore, if there is less water, then less heat will require to be extracted to freeze the fish. Since the fat content of oily fish is subject

to seasonal variations, it is safer to assume the same heat content figure used for lean fish in any calculation. This also ensures that the freezer capacity is adequate whatever the species of fish being frozen.

Calculation of freezing time

Freezing time can be calculated, but there is usually insufficient information available to make this calculation accurate. Calculated freezing times can be fairly accurate for uniformly shaped products such as blocks of fillets but, for other products with irregular shapes, calculation can only give a rough guide. The presence of wrappers and many other factors can make calculation of the freezing time difficult and unreliable.

Formulae that have been used for quick calculations in the past had to be simplified to make them practical. Thus they take little account of such things as the initial fish temperature. Most of them also assume that the fish has been chilled before freezing and that all of the heat is extracted at the initial freezing temperature. Calculated freezing times could therefore only be used to give an approximation of the true figure and could not be used for designing freezing equipment.

Modern computer techniques have now made it possible to calculate freezing times more precisely.

Plank's formula for calculating the freezing time of fish has been widely used in a variety of forms. It has proved to be particularly valuable in extending the results from experimental studies to cover a wide range of variables. Thus, if an accurately measured freezing time is known, others can be calculated if most of the freezing conditions are similar.

The more general form of Plank's equation for calculating freezing time is:

$$\text{Freezing time} = \frac{L}{V\Delta}\left\{\frac{PD}{f} + \frac{RD^2}{k}\right\}$$

where

L = Heat to be extracted between the initial freezing point and final temperature (kcal/kg)

V = Specific volume of fish (m^3/kg)

Δ = Temperature difference between the initial freezing point of the fish and the refrigerating medium (°C)

D = Thickness of product in direction of prevailing heat transfer (m)

f = Surface coefficient of heat transfer (including effect of packaging) (kcal/hm^2°C)

k = Thermal conductivity of frozen fish (kcal/hm°C)

P and R = Constants which depend on shape

From the above formula, it can be seen that freezing time is inversely proportional to the temperature difference and, depending on other conditions, it may also be nearly proportional to the square of the product thickness. This knowledge can be used to calculate other freezing times as shown in the examples that follow.

Measured freezing time. A measured freezing time of 3 h 20 m (200 min) is known for a 100 mm thick block of whole herring frozen in a VPF with a refrigerant temperature of -35°C.

Calculated freezing time - Example 1. What is the freezing time if all other conditions remain the same but the operating temperature is -25°C?

Fish freezes at about -1°C, therefore in the measured freezing time, the effective temperature difference is 34 degC (the difference between -35°C and -1°C). The effective temperature difference for the freezing time required is 24 degC (the difference between -25°C and -1°C). Freezing time is inversely proportional to the temperature difference, therefore, the freezing time with an operating temperature of -25°C will be longer than for a temperature of -35°C and can be calculated as follows:

$$200 \times \frac{34}{25} = 272 \text{ min or } \underline{4 \text{ h } 32 \text{ min}}$$

Table 6

Freezing times for fish products

Product	Freezing method	Product initial temperature (°C)	Operating temperature (°C)	Freezing time (h)	(min)
Whole cod block 100 mm thick	Vertical plate	5	-40	3	20
Whole round fish 125 mm, e.g. cod, salmon, frozen singly	Air blast 5 m/s	5	-35	5	00
Cod fillets laminated block 57 mm thick in waxed carton	Horizontal plate	6	-40	1	20
Haddock fillets 50 mm thick on metal tray	Air blast 4 m/s	5	-35	2	05
Whole lobster 500 g	Liquid nitrogen spray	8	-80	0	12
Scampi meat 18 mm thick	Air blast 3 m/s	5	-35	0	26
Shrimp meat	Liquid nitrogen spray	6	variable	0	5
Single haddock fillets	Air blast	5	-35	0	13
Packaged fillets 50 mm thick	Sharp freezer	8	-12 to -30	15	00
Packaged fillets 50 mm thick	Air blast 2.5 to 5 m/s	5	-35	5	15
Single tuna, 50 kg	Semi-air blast	20	-40	30	00 (-35)
Single tuna, 50 kg	Sodium chloride	20	-20	21	00 (-18)
Single tuna, 90 kg	Semi-air blast	20	-50 to -60	26	00 (-45)

Notes: (1) All freezing times are to -20°C at the fish centre unless otherwise stated. Other temperatures are given within the brackets after the freezing time.

(2) The times given are measured freezing times. In commercial practice, these times should be increased by a factor to allow for operating discrepancies.

Calculated freezing time - Example 2. What is the approximate freezing time if all other conditions remain the same and the block thickness is reduced to 75 mm?

Freezing time is directly proportional to the square of the thickness since in this case the surface heat transfer coefficient is high and the factor relating to the thickness of the block ($P \frac{D}{f}$) will be small. The new freezing time will therefore be calculated as follows:

$$200 \times \frac{75^2}{100^2} = 200 \times \frac{5\ 625}{10\ 000} = 112 \text{ min} = \underline{1 \text{ h } 52 \text{ min}}$$

The calculation of derived freezing times, as shown, is the best way of using freezing time formulae; when generally applied for predicting the freezing time, they can be extremely inaccurate.

Sample freezing times

The freezing times in Table 6 are observed times for a number of fish products and will give designers and operators some idea of what to expect in practice.

It should be noted that the initial fish temperature for all the examples given in Table 6 is about 5 to 8°C. This temperature is typical of what can be expected if fish are chilled before freezing and it makes allowance for the fish warming up during handling.

4. TREATMENT OF FISH AFTER FREEZING

As soon as fish are removed from a freezer, they should be glazed or wrapped unless they have been packaged before freezing and immediately transferred to a low temperature store. When it is known that storage will be for a short period only, glazing or wrapping may not be necessary or practical. Blocks of whole cod frozen at sea, for instance, are usually transferred to the cold store without a protective wrapper or glaze but this may be added later before long term storage on shore. However, even during relatively short terms of storage, fish without a protective wrapper or glaze can be severely dehydrated in a poorly designed or operated store.

Glazing

The application of a layer of ice to the surface of a frozen product by spraying, brushing on water or by dipping, is widely used to protect the product from the effects of dehydration and oxidation. The ice layer sublimes rather than the fish below and it also excludes air from the surface of the fish and thereby reduces the rate of oxidation. Heat added by the glazing process is often considerable and the fish may require to be recooled in a freezer before being transferred to the cold store.

In order to form a complete and uniform glaze on the surface of the fish, the glazing process requires to be closely controlled. The amount of glaze applied depends on the following factors:

Glazing time
Fish temperature
Water temperature
Product size
Product shape

Glazing by dipping in a container of water is not recommended. The initial temperature of the water may be relatively high; this is reduced as glazing proceeds and the thickness of glaze will therefore vary. The glaze on IQF fillets has been shown to vary between 2 and 14 percent using this method, even when the immersion time was kept constant. In practice, the time will not be constant and this will be another variable which will give rise to even more irregular glazing. The water may also become contaminated after some time; therefore, the method is also not recommended for this reason. If a dipping method is used to apply a glaze, the container should be continuously supplied with water and fitted with an overflow.

Spray glazing methods are suitable, but again it is difficult to obtain a completely uniform glaze and a good deal of effort is required to turn over the fish to ensure that all surfaces are treated.

The dip-spray glazer shown in Fig. 34 has a number of features which enable a complete and uniform glaze to be applied.

(1) A constant speed belt will ensure a fixed time in the glazing zone;

(2) The water level in the trough is adjustable to ensure that the lower surface is glazed but the frozen product does not float;

(3) The overhead spray provides a constant supply of make-up water and glazes the upper surface of the product;

(4) The adjustable baffle may be used to rearrange overlapping fish on the belt so that each fish is totally exposed;

(5) The method uses half the quantity of water required for automatic glazers using open mesh belts and operated with sprays from above and below.

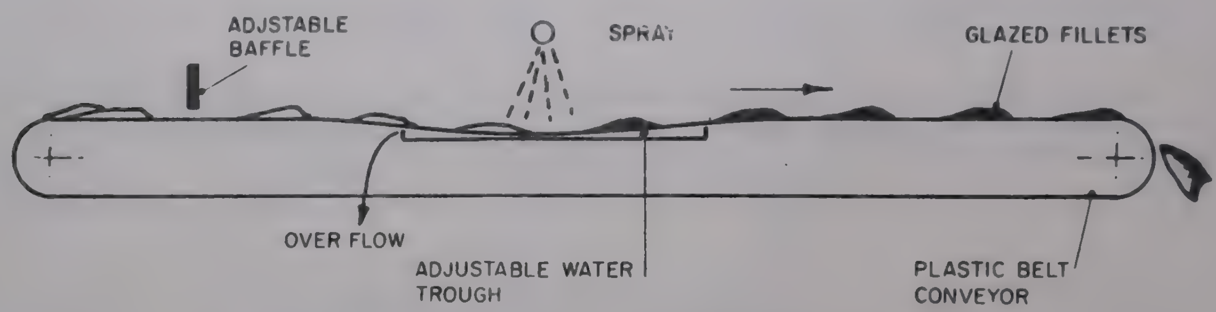

Fig. 34 A dip-spray glazer for glazing fish

Glazing when the fish temperature is at -70°C or lower results in a glaze which is fractured and broken due to thermal stress during the formation of the ice. This glaze is easily dislodged during subsequent handling. If the fish are immersed in the glaze water for too long, a thick glaze is formed but the equilibrium temperature of fish and ice is high and only slightly below 0°C. This glaze will be soft and easily dislodged during subsequent handling.

Good glazing practice can be benificial particularly when other aspects of storage and transport are far from ideal, but poor glazing involving partial thawing of the fish and slow refreezing in cold storage may do a good deal more harm than good.

Packaging

For the protection of retail consumer packs and also for aesthetic reasons to promote sales, wrapping should be provided. As far as possible the packaging should be airtight to prevent oxidation of the product. The wrapping material should also have a high resistance to the penetration of water vapour in order to protect the fish from evaporation during storage. The wrapper should also be well fitted to the product. Air within the wrapper allows oxidation of the product to proceed. The degree of impermeability of a wrapper to both air and water vapour depends on the expense that can be allowed for the packaging material. Where the qualities of a wrapper for protection of the product and for sales appeal are in conflict, an inner and outer wrap may be used in order to satisfy both requirements. Among the materials used for packaging fish are waxed or plastic-coated cartons. These may be used with or without an inner sealed pack or protective overlapping lining. A variety of pouches or bags made from treated paper, plastics or aluminium foil are also widely used. The type of pack used depends to a great extent on whether the product is to be wrapped before or after freezing.

Freezing times can be considerably extended by the insulating effect of the wrapper; therefore, consideration should be given to whether the fish should be wrapped before or after freezing. Loosely packed fish leave air spaces within the pack and the trapped air provides an additional resistance to heat transfer. It is not unknown for freezing times to be doubled due to the insulating effect of this trapped, stagnant air. Fish packed in this manner may, however, be frozen a good deal more quickly in an air blast freezer if the lid is left off the pack until freezing is complete to allow air to circulate within the pack.

Freezing fish and then packaging or wrapping is not often an acceptable way of reducing long freezing time. Frozen fish are stiff and unyielding and therefore they cannot be readily made into a compact package. For this reason it is usually only IQF products that are frozen before packing.

Many catering packs consist of fibreboard outer cases for fish that have already been protected by glazing and in these cases it is usual to use an inner overlapping lining.

Large single fish are more conveniently glazed than wrapped.

Interleaving of good quality waxed paper or plastic material between fish in consumer packs allows individual fish to be separated from the pack while still frozen. This type of pack is known as a shatter pack.

Fish that are bulk frozen to be further processed after cold storage are better to be glazed rather than wrapped unless, as is the case with herring, a wrapper is required to protect the fish during handling in the frozen state.

Pallets with neatly stacked blocks of frozen fish can be wrapped with a suitable plastic material after palletization. This considerably reduces exposure of the fish to the store air, thus reducing the rate of dehydration.

Transfer to store

The time between unloading the product from the freezer and putting it into cold storage should be as short as possible. The surface temperature of the product can quickly rise to the thawing region at ambient conditions, particularly with small pieces of fish such as individually frozen fillets and shrimp. Any packaging or processing, such as glazing, carried out between freezing and cold storage, should be done in premises kept as cool as possible and always out of direct sunlight and other radiant heat sources such as room heaters. Care must be taken not to damage frozen fish during transit from freezer to store. Although the product seems robust, it is easily damaged by rough handling. In many cases, the damage done may not show until the fish is thawed. This damage may mean that extra trimming of the fish is required or the fish may look unsightly and have to be sold at a lower price. Mechanization of the packaging and glazing process can help in getting the product to the store in good condition.

5. COLD STORES

Recommended storage temperature

The spoilage of fish due to protein denaturation, fat changes and dehydration can all be slowed down by reducing the storage temperature.

The FAO Code of Practice for Frozen Fish recommends that frozen fish products should be stored at temperatures appropriate for the species, type of product and intended time of storage.

The recommended storage temperature for all fishery products in the U.K. is -30°C and this temperature has also been adopted throughout Europe by at least one large public cold store operator. Spoilage by bacterial action in any practical sense is completely arrested at this temperature and the rate at which other undesirable changes proceed is greatly reduced. Some products can be stored safely at higher temperatures than the -30°C recommended providing storage is only for a short period. Since it is not always possible to guarantee that a product will stay in storage no longer than originally intended, it is generally safer to use the lower recommended temperature.

The International Institute of Refrigeration recommends a storage temperature of -20°C for lean fish such as cod and haddock and -30°C for fatty species such as herring and mackerel. The code also recommends that for lean fish intended to be kept in cold storage for over a year, the storage temperature should be -30°C.

It is seldom that a cold store operator can be sure that he will store only one species or type of fish, and that storage will only be for a limited period. Cold stores built for storage of fish should preferably be able to operate at -30°C but it may be appropriate to operate at a higher temperature if circumstances and relevant codes or recommendations allow.

It has been calculated by an eminent authority on cold store design that under specific conditions, the total cost of operating a cold store at -30°C is only 4 percent higher than when operating at -20°C although the corresponding percentage increase in running costs will be higher.

The difference between total cost and running or operational cost will be made clear to the reader by examining the cold store costing detailed in Chapter 7. The total cost is the figure used to calculate the cost of the cold storage operation and it is therefore more realistic to use this value in

making comparisons. It can be seen from Table 7 that, although under certain circumstances fish may be kept at higher temperatures, there is a distinct advantage in keeping fish at -30°C and it is possible that the advantage of improved quality can more than offset the additional cost of storage at the lower temperature.

Table 7

The cold storage life of fish

Stored at	-10°C		-20°C		-30°C	
Type of fish	Good	Inedible	Good	Inedible	Good	Inedible
White fish (gutted)	1 mo	4 mo	4 mo	15 mo	8 mo	More than 4 y
Herring (ungutted)	1 mo	3 mo	3 mo	6 mo	6 mo	More than $1\frac{1}{2}$ y
Smoke-cured white fish	1 mo	3 mo	$3\frac{1}{2}$ mo	10 mo	7 mo	More than 1 y
Smoke-cured herring	3 wk	2 mo	2 mo	5 mo	$4\frac{1}{2}$ mo	More than 9 mo

Table 7 shows the potential storage life at various temperatures for various types of fish and fish products. It is based on the results of experiments made over a number of years and the fish used were stowed in ice for no more than 24 h between catching and freezing. All but the smoked fish were glazed, packed in wooden boxes lined with parchment paper and stored. Store temperature control was within ±0.5 degC of the stated values. The qualification "inedible" in Table 7 indicates that the product becomes distasteful to a consumer accustomed to fresh fish.

Precautions taken in these experiments were more rigorous than can normally be achieved in commercial practice, therefore the figures presented in the table should be regarded as the best than can be achieved. Shorter storage times would therefore be expected under normal commercial practice but in stores where the maximum storage time is a good deal less than those in the table, the fish quality at the time of freezing may have been inferior or storage conditions were poor.

Another advantage of operating the cold store at -30°C is that there is more scope for handling the frozen fish during subsequent handling and transporting between stores; the lower temperature means that a temperature rise during this period will be less critical.

Factors limiting storage life

Protein changes. Fish proteins become permanently changed during freezing and cold storage and the speed at which this denaturation occurs depends very largely upon temperature. At temperatures not very far below freezing point, -2°C for example serious changes occur rapidly; even at -10°C, the changes are so rapid than an initially good quality product can be spoilt within a few weeks.

The rate of deterioration due to protein denaturation, however, can be slowed by ensuring that storage is at as low a temperature as possible.

Fat changes. The fat of fish may become unpleasantly altered during cold storage.

The addition of chemicals called antioxidants at some stage before cold storage has so far proved ineffective; but fatty fish can be protected to some extent either by glazing or by packaging in plastic bags sealed under vacuum.

These oxidation changes take place more rapidly at higher temperatures and storage at a low temperature is an effective means of slowing the rate of spoilage by this method.

Colour changes. The quality of fish is often judged by appearance, and colour changes which are not otherwise significant can result in fish being downgraded. The changes in the fish flesh which bring about these colour changes are also retarded at lower temperatures.

Dehydration changes. Dehydration of the product is probably the major concern of the cold store operator and the rate of drying can be linked with a number of factors in cold store design and operation.

When fish get badly dehydrated in cold storage, the surface becomes dry, opaque and spongy. As time progresses, these conditions penetrate deeper into the fish until it becomes a fibrous, very light material. Visible effects of severe dehydration on the surface of the fish are known by the term "freezer burn". This is an unfortunate choice of term since the effect is unlikely to result from freezing in a properly designed freezer, and appears only after comparatively longer periods of storage in a cold store.

Frozen fish may dry slowly in cold storage even under good operating conditions. This is undesirable for reasons other than the most obvious one that the product will lose weight. Drying also accelerates denaturation of the protein and oxidation of the fat in the fish. Even totally impervious wrappers used to protect the product do not give full protection if the cold store operating conditions are favourable for desiccation within the pack. In-pack desiccation prevails when there is some free space within the wrapper and the temperature of the store fluctuates. When this occurs, there will be times when the wrapper is colder than the fish and moisture will then leave the product and appear as frost on the inner surface of the wrapper. The total weight of the product and package will not change but if the in-pack dehydration is severe, the fish will have the quality defects of excessive drying.

Store operating conditions

The factor which determines the rate at which exposed frozen fish dehydrate in a cold store is the ability of the surrounding air to transport water from the surface of the fish. The drying effect of the air depends on a number of factors. Examination of Fig. 35 shows that air at -20°C can contain three times as much water vapour as air at -30°C. The potential drying effect of the air is therefore greater at the higher temperature. The surrounding air will only dry the fish if its relative humidity is less than 100 percent. The lower the relative humidity, the higher the drying potential of the air since the more water vapour it can take up from its surroundings before it is saturated. Drying is therefore more likely when the air temperature is high and the relative humidity is low, and both these conditions are more likely if heat is added to the store. This heat can enter the store in many ways. It can be added by the product, other products, heat leak through the insulation, lights, air ingress, a person working in the store, and so on.

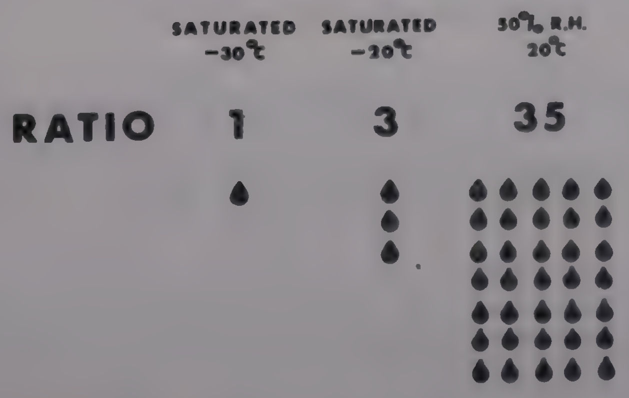

Fig. 35 Diagrammatic illustration which shows the relationship between the moisture content of air at various significant conditions

Good storage conditions can therefore only be attained if heat leak is kept to a minimum and any heat that does enter the store is immediately transferred to the refrigeration system.

The measured rate of dehydration from the surface of exposed frozen fish has been found to vary by a factor of 100 between a well designed and operated store and one that is badly designed and operated.

The worst stores are generally those which are frequently loaded with quantities of unfrozen or incompletely frozen fish. This imposes a high heat load and results in the dehydration of other products in storage. Under some of the very poor storage conditions measured, glazing of otherwise unwrapped fish would only provide protection against dehydration for two weeks or less.

The important factors to be kept in mind when designing and operating a cold store are therefore:

Low temperature
Uniform temperature
Steady temperature
Good air distribution
Minimum rate of air circulation
Minimum heat ingress

The type of cooler, cooling arrangement and method of operating the cooling system are also factors which relate to the quality of the store.

Types of cold store

Jacketed cold stores. The jacketed store system (Fig. 36) is an ideal method of construction but it is costly. The inner storage space must be completely isolated from the jacket air. The inner lining must therefore be constructed with a material which does not allow an exchange of air, and joints must be well sealed. The jacketed store construction ensures that temperature differences within the storage space are small and since heat ingress is kept to a minimum, high relative humidities are attained and the rate of dehydration is low. The jacketed system of storage does not require internal fans for air circulation and this is another factor that contributes to its good quality. This system has not been used widely for commercial stores principally because of the cost of construction, and the jacketed system is also not suitable if a high product refrigeration load is unavoidable.

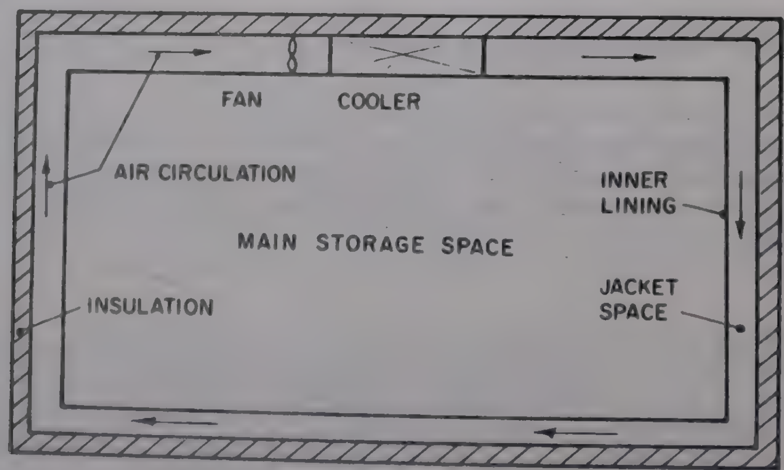

Fig. 36 Jacketed cold store

Gridded cold stores. Plain pipe grids on the roof and walls of a store generally give good storage conditions. Heat entering the store through insulation is immediately transferred to the refrigerant without affecting the product. Air is not circulated by fans and, because the pipe grids cover all the walls and ceiling, temperatures within the store are fairly uniform. The rate of heat transfer to plain pipe grids only changes slowly as frost builds up on the surface of the coils, and frequent defrosting is therefore unnecessary. Stores of this type may operate for months without the need for defrost.

The main disadvantage of pipe grids is high cost. One estimate is that a gridded store will cost 33 percent more than a store operated with unit coolers with fan circulation. The grid system also means that the refrigerant charge is considerable. Apart from the extra cost of the refrigerant, certain difficulties arise when repairs and maintenance are necessary. The system must be provided with a vessel to hold the refrigerant charge when the cooler requires to be emptied. Pipe grids and the refrigerant contained in them, add a good deal of weight to the internal store structure; therefore, extra costs are incurred in the construction of the store.

Finned grid stores. If pipe grids are finned, the length of pipe required to provide the necessary heat exchange surface is greatly reduced and roof grids only may be sufficient. The cost of a finned grid installation is therefore less than for installation with plain pipe grids and they compare favourably in cost with stores using unit coolers. Finned grid stores, however, will not have the advantage of plain pipe grid stores in two respects. The grids do not cover the walls and therefore storage conditions will not be quite as good as with plain grids. Defrosting finned grids is also difficult and the period between defrosts will be shorter.

The frost on finned grids must never be allowed to bridge the gap between the fins. If this happens, the heat transfer surface will be reduced by a ratio of 10 to 1 or even more, and the temperature of the store will rise. The fins cannot be brushed free from frost and if a hot gas defrost is used, water will drip from the grids and freeze on the product. The only effective solution is to defrost when the store is empty. Since this may not occur at convenient intervals, gridded cold stores are often operated long after a defrost is necessary and the store temperature rises above the design value.

Stores with unit coolers. The most widely used method of cooling modern cold stores is by means of unit coolers with fan circulation of the air. This type of cooler is generally the cheapest to install; it contains a relatively small charge of refrigerant, it can be readily defrosted without interfering too much with the store conditions and it does not require a heavy structure for supporting the units. The main disadvantage is that many designs using this type of cooling unit do not allow for uniform distribution of the air within the store. This gives rise to poor storage conditions particularly in some areas of the store where the air circulation is either too high or too low (Fig. 37).

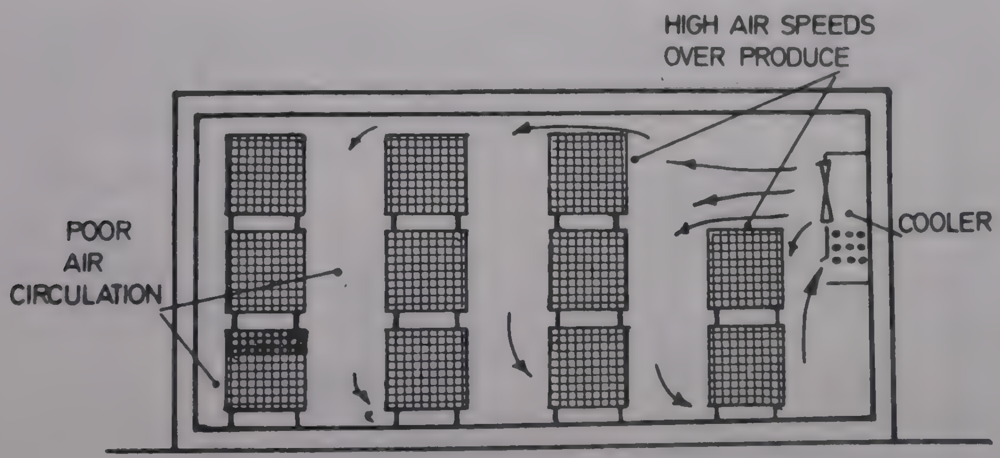

Fig. 37 Uneven air distribution in a store with a unit-cooler with fan circulation

Unit coolers can be arranged to give relatively good storage conditions. The main requirement is that the air should be ducted to give uniform distribution throughout the store. Diagrammatic illustrations of some recommended arrangements to achieve this purpose are shown in Figs. 38 and 39. The defrost procedure will have a minimum effect on the store if the cooler units are located outside the main store and, if possible, isolated during the defrost procedure (Fig. 40).

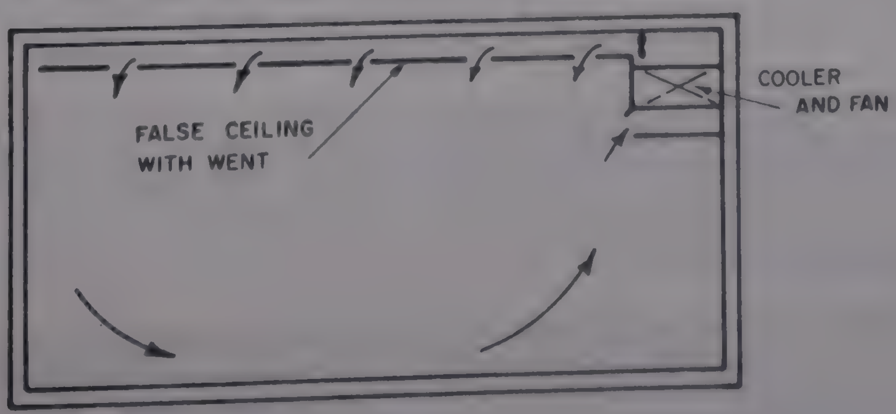

Fig. 38 Cold store with a false ceiling and vents to give uniform air distribution

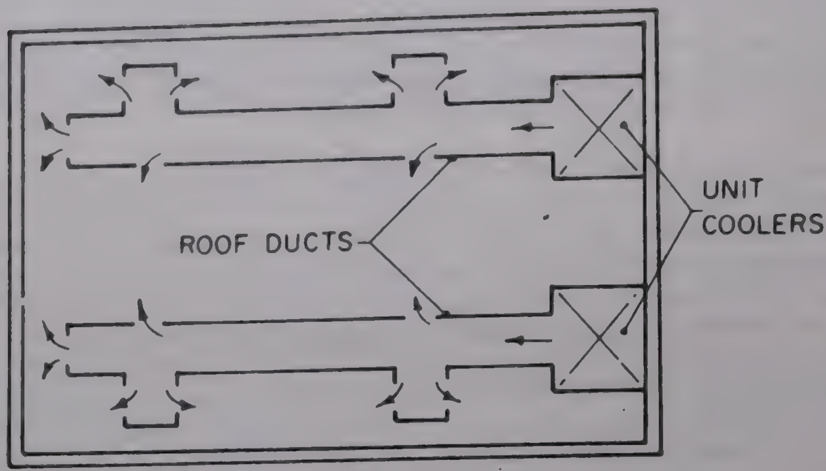

Fig. 39 Plan view of a cold store using roof ducts to give uniform air distribution

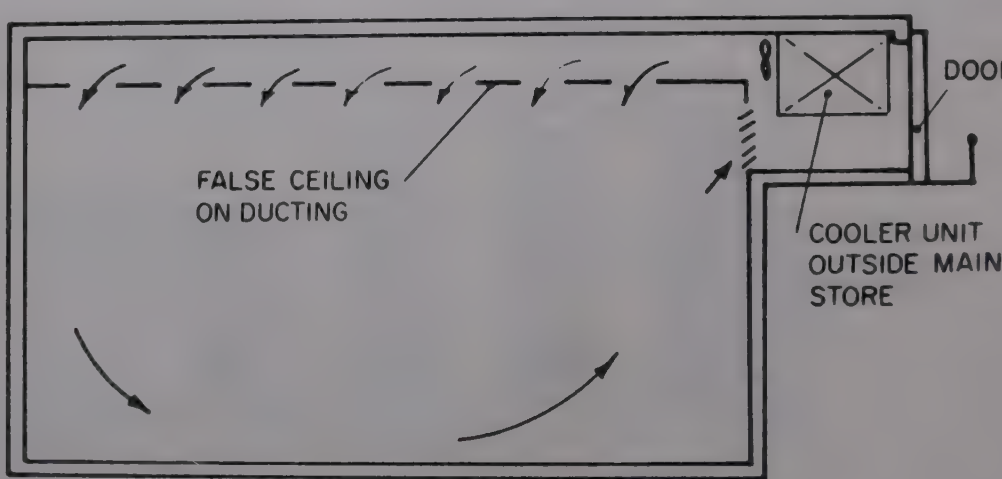

Fig. 40 Ducted-air cold store with cooler unit outside the main store

Multiple unit systems are usually better than large single units for a number of reasons. A multi-unit system gives some insurance in case of breakdown. The store can usually be maintained at its design value without the need for all units to be in operation provided there is not a high additional refrigeration load due to product and too heavy traffic in and out of the store. Multiple units also allow each unit to be defrosted in sequence and this arrangement has the least effect on storage conditions. If a hot gas defrost system is used, then a multiple unit system is essential so that the units in use provide the necessary refrigeration load for the refrigeration compressor.

With small units, electrical defrosting is more common. The defrosting of unit coolers in small cold stores is usually automatic and operated by a time clock. With this mode of operation, the timing of defrosts should be arranged to coincide with times when the refrigeration load is low, usually during the night.

Factors affecting storage conditions

The size and shape of a cold store can be related to the rate of drying of the products. A small cold store has a greater heat leak in proportion to the quantity of product in the store since the volume of a store increases at a greater rate than the surface area. This means that one large store is likely to provide better storage conditions than two smaller stores with the same capacity.

In order to keep the heat leak through the insulation to a minimum, the ideal shape would be a cube - this provides the greatest storage space for the least surface area. Goods can only be stacked up to about 8 m high with the aid of fork lift trucks; therefore, in order to obtain the ideal cube shape for a large store, the store must be built with multiple floors. Multiple storey stores however give rise to problems with handling goods in and out of the store. This is particularly relevant to general purpose stores which have a heavy traffic in and out. Modern stores are therefore nearly all single-floor units with a large enough frontage to allow easy access for loading and unloading.

Cold stores may be built against a rigid structure or may be free-standing, and there are obviously basic differences in the methods used to construct these different types. In a few cases, cold stores for frozen food, not specifically for frozen fish, have been constructed underground, and this type of construction may be considered. However, the rock of suitable quality on the intended site and many other conditions have to be met for an underground cold store to have an advantage over a more conventional structure above ground. Details on methods of cold store construction are outside the scope of this document but some requirements justify special mention.

Vapour barriers. The water contained in the air within a cold store is a good deal less than the water held in the air outside (Fig. 35). Water in the air gives rise to a pressure and together with the other gases present, such as oxygen and nitrogen, account for the atmosphere pressure that we are all familiar with. The partial pressure exerted by the water vapour is proportional to the quantity of vapour present and the vapour in the air will tend to migrate from areas of high partial pressure to areas of low partial pressure. Hence, there is a tendency for moisture in the ambient air to pass through the insulation of a cold store to the area of low partial pressure within (Fig. 41). When this vapour is cooled, it condenses and when it reaches the point where the temperature is $0^{o}C$, it freezes to form ice. This process will continue over a long period of time and the build-up of ice will eventually affect the insulation properties of the cold store wall and also weaken the structure of the wall or building. Unfortunately, the outward effects of this build-up of ice may not show for some time, long after the builder's guarantees have become invalid.

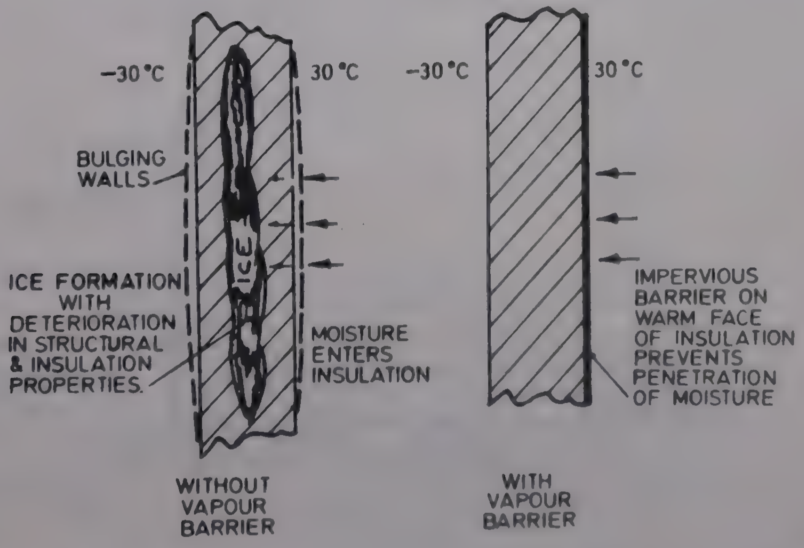

Fig. 41 Diagram illustrating the function of a cold store vapour barrier

To prevent this type of destruction to the store insulation, a vapour barrier has to be provided on the warm side of the insulation. This vapour barrier must be complete and cover all walls, the roof and the ceiling. For stores constructed against a building wall, this may be formed by applying at least two coats of a suitable bituminous sealing compound. With prefabricated stores, a vapour barrier is already provided with the individual sections, usually an outer facing of sheet metal, and only the joints in this case require sealing.

It must be remembered that water vapour behaves like a gas and it is not sufficient merely to make the outer surface waterproof; overlapped joints, for instance, must be sealed.

Foundations and frost heave. Low temperature stores built directly on the ground may require special precautions to prevent the build-up of ice below the cold store floor. The ice formation is known as "frost heave" and in particularly bad cases, it can lead to the complete destruction of the store and structure of the building (Fig. 42).

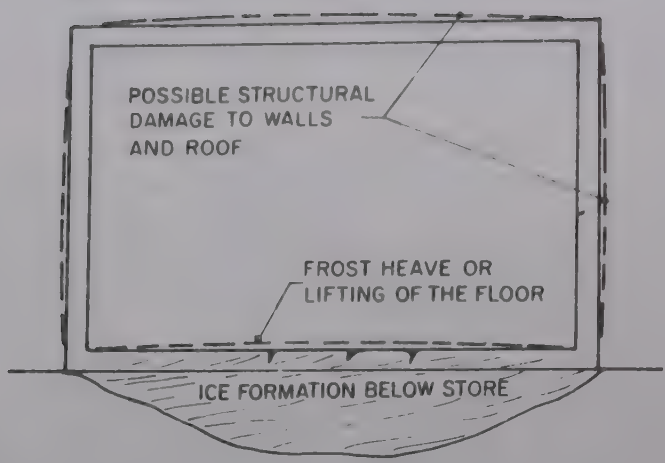

Fig. 42 Ice formation resulting in the frost heave of a cold store

The conditions that give rise to frost heave are rather complex since they are related to the type and texture of the soil, the insulation properties, the availability of moisture, the dimensions of the store, seasonal climatic variations and other factors.

Two methods of preventing frost heave are commonly used. The ground below the store can be heated either by a low voltage electrical mat in the cold store foundation or by circulating a heated liquid such as glycol through a pipe grid built into the foundation (Fig. 43). The heat for the glycol is usually obtained from the compressor hot gas through a heat exchanger.

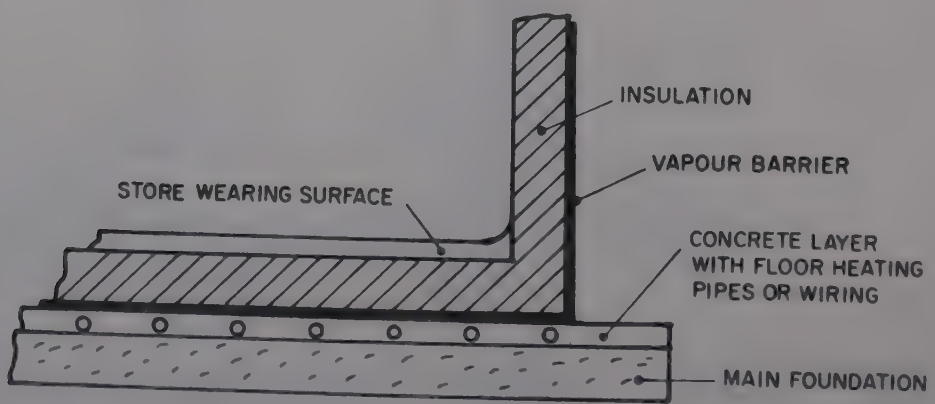

Fig. 43 Frost heave prevention using floor heating

Another method of preventing frost heave is to leave a space below the store for ventilation (Fig. 44). The level of the floor of a cold store is usually arranged to suit the unloading and loading of vehicles. The additional height required for this facility leaves plenty of height for an air ventilation space below the insulation. If there is any danger of flooding, cold store floors will be built above the likely water level and again there will be an opportunity to leave an air space for ventilation. This ventilation arrangement should be clearly defined and not blocked at a later date when the main function of the air space has long been forgotten.

The provision of a vapour barrier and the provision of equipment for the prevention of frost heave are probably the two most important requirements in the construction of a cold store.

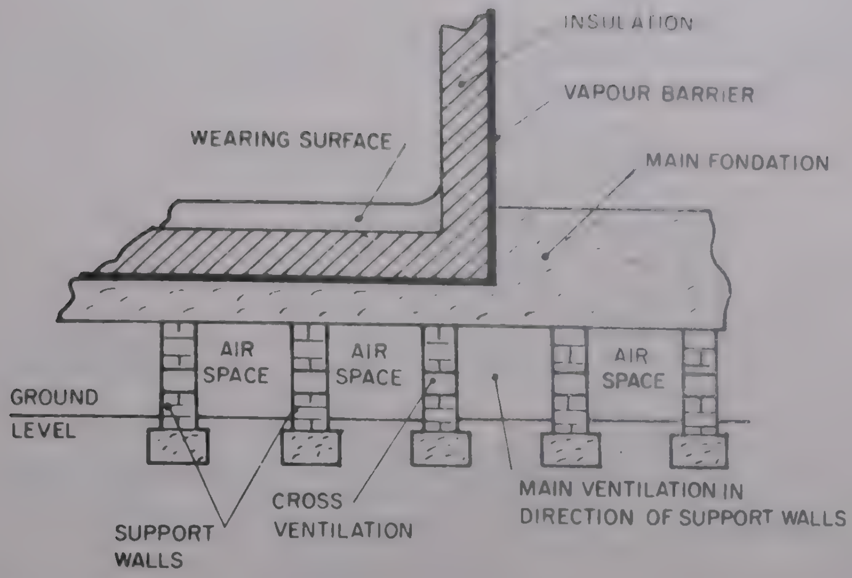

Fig. 44 Frost heave prevention using underfloor ventilation

<u>Air ingress</u>. Air entering the store means not only the addition of heat but also moisture. This moisture will be deposited as frost on any cold surface and will eventually finish up on the surface of the cooler. Excessive air exchange should therefore be prevented to keep the cold store temperature steady and also reduce the frequency of defrosting. Small air locks have been used to prevent the free flow of air in and out of the store but they are not popular with cold store operators (Fig. 45). The air-lock space often does not allow complete mobility and unless this condition can be met, both doors are left open. The air lock will therefore serve no useful purpose and merely occupies valuable space.

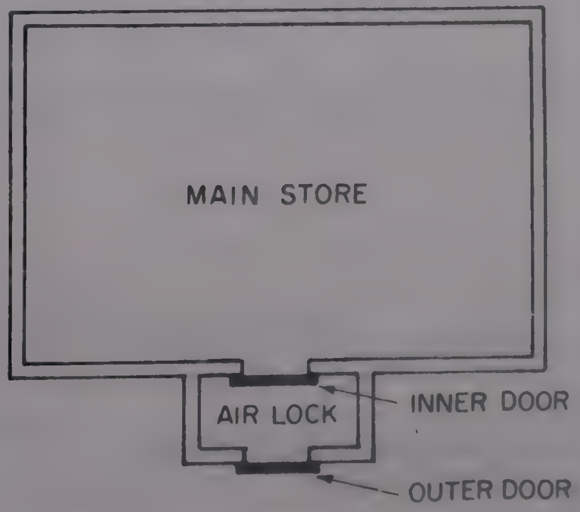

Fig. 45 Illustration of a cold store air lock

A curtain of air blown downward or from the side of the doorway can reduce the exchange of air when the door is open. These air curtains, as they are called, can be a useful aid when the door is opened for short intervals. However, they are often abused and doors are often left open for long periods.

Hatches can be used to reduce air ingress when a product is being loaded or unloaded. Hatch openings should be as high up in the store wall as possible to prevent excessive loss of cold air. Portable conveyors can also be used to speed up the transfer of produce.

Store door openings can be fitted with an inner curtain made from overlapping strips of synthetic material suitable for use at low temperatures (Fig. 46). This reduces the air exchange considerably without interfering too much with traffic but the curtain must be maintained in good order and, as with the air curtain, not abused by leaving the outer main door open.

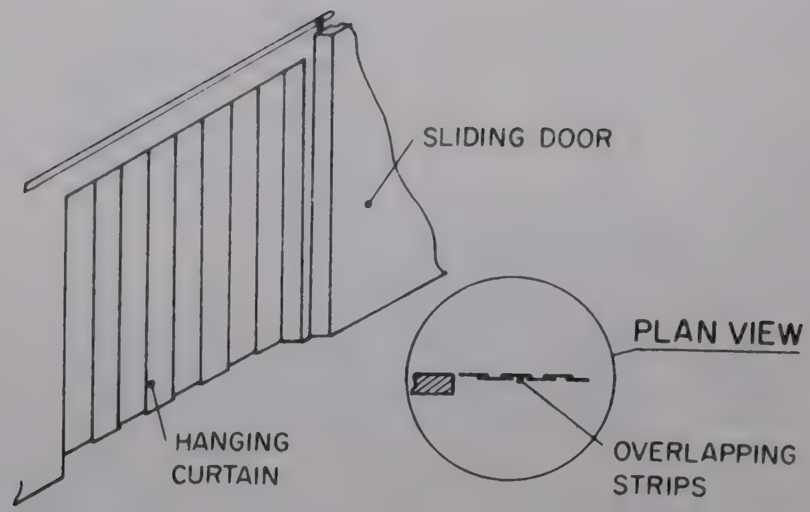

Fig. 46 Inner curtain of flexible strips used to reduce air exchange

Large stores are fitted with power-operated doors which can be quickly opened and closed, usually by operating pendant switches outside and inside the doorway. Because this system is easy to operate even from a moving fork lift truck, door opening times are kept to a minimum. Overlapping strip curtains can also be used to reduce the air exchange.

Product handling and storage

Large stores are provided with a loading platform which can be adjusted to accommodate varying vehicle heights (Fig. 47). This platform must also provide adequate space for quick sorting and manoeuvring of goods in and out of storage. A platform width of 8 to 10 m may be necessary for this purpose. The unloading area should also be roofed over so that goods being transferred in and out of the store are protected from direct sunlight and rain. This cover also protects the doorway, which may ice up if it is exposed to rainfall.

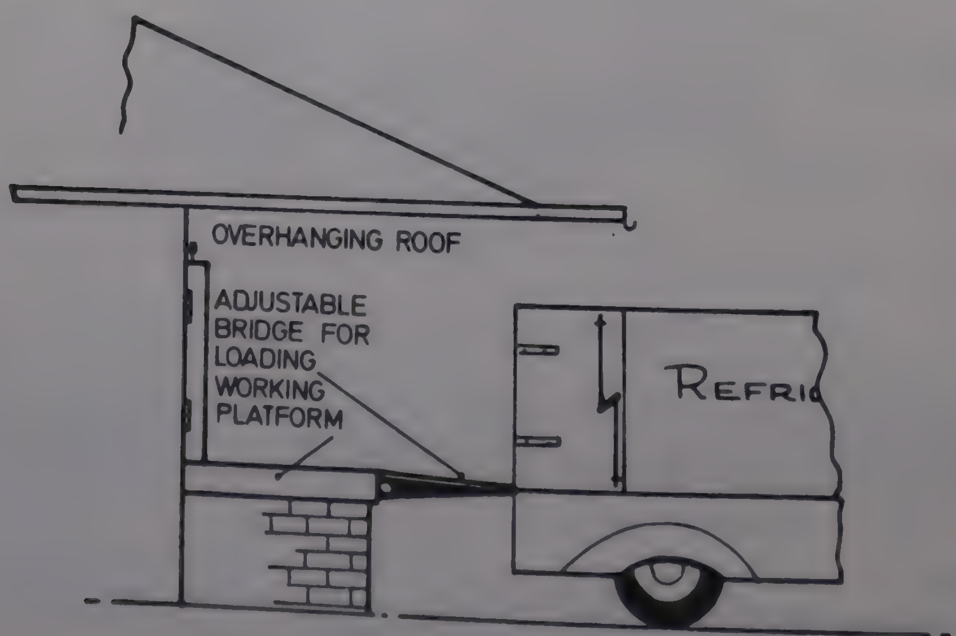

Fig. 47 Loading platform for a cold store

In hot countries, handling frozen fish outside the low temperature storage space can quickly result in exposed fish being warmed and even thawed. The provision of a refrigerated working area and loading dock is therefore recommended for prestorage sorting and the assembly of packages for shipment. This loading dock should be totally enclosed, insulated and refrigerated to a temperature of about 10°C. The area of this dock will depend on the amount of traffic and the type of store operation. In a public store where a good deal of sorting is required, this area may be as much as 25 percent of the store floor area as shown in Fig. 48.

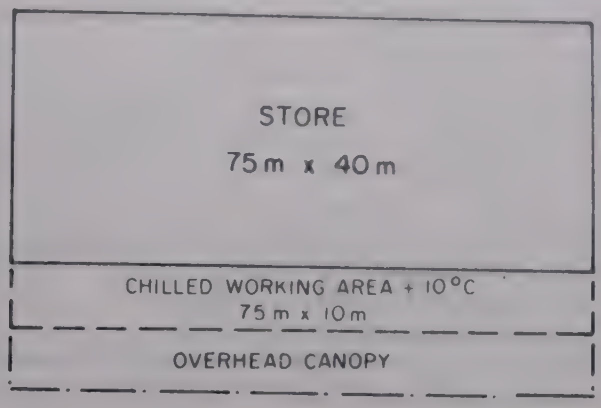

Fig. 48 Cold store with a refrigerated working area

In addition to providing a chilled working space, this refrigerated dock will act as a large air lock between the outside air and the low temperature air within the store. As much as 80 percent of the moisture in the ambient air will be removed by the cooler in this space and a good deal of precooling will be done before this air enters the main store. This will reduce the defrost requirement for the store coolers and generally result in a more stable and lower storage temperature.

The means of transporting goods in and out of the store and within the store depends on the goods being handled, the type of cold store, the height of store, the need to reduce labour costs and many other factors that may only have a local significance.

A list of some of the equipment that may be considered is given below:

(a) Transport on the level

Two-wheeled trolleys
Manhandled platform trolleys
Self-propelled platform trolleys
Manhandled or self-propelled transporting pallets
Belt, chain or roller conveyors, either gravity or self-propelled

(b) Equipment for vertical handling

Continuous elevators of various types
Platform elevators
Cranes
Gantries
Hand-stacking equipment
Various types of mechanized stacking equipment

(c) Equipment for both horizontal and vertical movements

Fork lift trucks, hand or power operated
Adjustable mechanized conveyors

Whenever possible, pallets should be used for storage of the product. These divide the goods into unit loads which can be transported, stacked and retrieved with a minimum of effort. Regular-shaped packages or blocks can be readily palletized. Loose fish, such as those broken from blocks and other irregular-shaped products, can also be stored in pallets with wire mesh walls. Pallets should not be stacked so that the base of one pallet rests on the produce below. Each pallet should therefore be

constructed with a framework to support the pallets above. Framed pallets can be stacked five high with safety, but only if they are correctly stacked.

There has been a recent tendency to provide pallet racking especially in public stores where it is often necessary to remove a pallet from the bottom of a stack. In a pallet racking system, the individual pallets do not rest on the pallets below but are supported on a framework. This allows any individual pallet to be added or taken away without the need to break down the stack. In ultramodern stores, pallet racks have been motorized so that there is no need to provide so many passages within the store. The racks are moved as required to allow access to individual rows. This degree of mechanization would only be employed when store utilization and quick handling are critical factors.

Attempts have been made to standardize pallet sizes but this has not yet become worldwide. Pallet dimensions of 800 x 1 200 mm and 1 000 x 1 200 mm have been widely used but the final choice will depend on local circumstances depending on such factors as the degree of interchange of pallets outside the store, vehicle and package dimensions, and other transport and storage considerations.

When a fully accessible palletized system is not used, the product should be loaded in the store so that a first-in first-out system can be operated. This ensures that there is a correct product rotation, and storage times are not unnecessarily long.

The width of passageways will depend on the equipment used for transporting and stacking the product. Details of the space requirements of this equipment must therefore be obtained before a decision is made on the size of store required.

Produce should not be stacked directly against the walls or floor of the store; otherwise heat entering the store through the insulation will pass through the produce before being transferred to the cooler.

This transfer of heat through the product is one of the factors that increase the rate of dehydration of stored produce. In order to prevent this transfer of heat through the product, the following spaces should be left between the floor, walls and roof coolers:

Floor	-	100 mm
Walls	-	200 mm
Ceiling coolers	-	500 mm

The above clearances allow for free circulation of air and also a degree of manoeuvrability which will reduce the possibility of damage to the store structure. The floor clearance is usually provided for by the pallet base (Fig. 49).

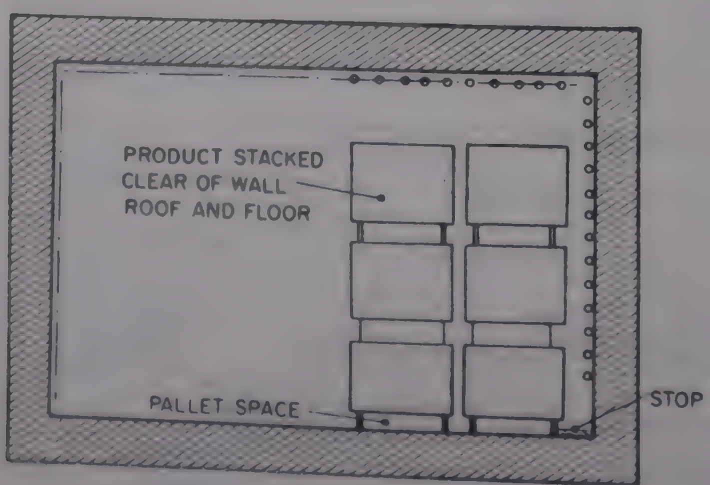

Fig. 49 Correct stacking in a cold store

Stores with plain walls will require to be fitted with battens or some other kind of superficial structure to ensure that the product does not come into contact with the stone walls. Often a kerb around the wall which prevents close stacking is sufficient.

Cold store layout. The layout of a store is determined by the type of produce, packaging, method of palletization, accessibility required and the equipment used for handling.

Passageways should be clearly defined and in the interests of safety and quick handling, these should be kept free from obstruction at all times.

The floors of large stores are often marked off with a grid and the grid spaces numbered so that the location of goods can be recorded thus enabling quick retrieval.

Products stored near the doorways will come into frequent contact with warm moist air entering the store when the door is open. Some form of partition may be used to reduce the effect of this warm air on products stacked in this area.

Calculation of cold store refrigeration load

A good deal of experience is required to make a correct calculation of a cold store's refrigeration requirement and this should therefore only be done by a qualified person. The following calculation is not complete but it serves two purposes. It allows the reader to make a similar calculation for his own store and thereby obtain an approximate refrigeration requirement. It also helps the reader to appreciate the number of factors that have to be taken into account in calculating the heat load and also gives him some idea of their relative importance.

One important heat load that has been omitted in the calculation is the heat gain due to solar radiation. This factor depends on a number of conditions which are related to both the location of the store and its method of construction. In some cases, solar heat load may not be significant but in other instances, precautions may be necessary to reduce its effect.

Cold store refrigeration load

Specification

Capacity 20 m x 10 m x 5 m = 1 000 m^3
Insulation thickness (0.25 m of cork or equivalent)
Total store surface area (771.5 m^2)
Maximum ambient temperature (35°C)
Store temperature (-30°C)

Load calculation

(1) Insulation heat leak through walls, roof and floor

Conductivity of cork	0.037 kcal/h m°C
Temperature difference between 35°C and -30°C	= 65 degC
Thickness of cork	0.25 m
Surface area of store	771.5 m^2

Heat leak $= \frac{771.5 \times 65}{0.25} \times 0.037 = 7\,476$ kcal/h

(2) Air changes

Average of 2.7 air changes in 24 h

Store volume	1 000 m^3
Heat gain (35°C and 60% R.H. air)	40 kcal/m^3

Air change heat gain $= \frac{1\,000 \times 2.7 \times 40}{24} = 4\,500$ kcal/h

(3) Lights (left on during working day)

1 000 W = 860 kcal/h

(4) Men working

1 man working at $-30^{\circ}C$ gives off	378 kcal/h	
2 men working is equivalent to		756 kcal/h

(5) Product load

5.5 kcal/kg for fish load at an average temperature of $-20^{\circ}C$		
Fish loaded per day	35 000 kg	
Product load =	$\frac{35\ 000 \times 5.5}{24}$	= 8 020 kcal/h

(6) Fan load

3 x 1/3 hp		= 923 kcal/h

(7) Defrost heat

1 defrost of 8 440 W for 1 h (recovered over 6 h)		= 1 209 kcal/h
Total calculated refrigeration load (sum of Items 1 to 7)		= 23 744 kcal/h
Total refrigeration requirement with allowances	$23\ 744 \times \frac{24}{18}$	= 31 658 kcal/h

If a pump is used to circulate refrigerant, the heat equivalent must be added to the capacity of the refrigeration condensing unit but not to the capacity of the room cooler.

The minimum refrigeration requirement will be when there is only an insulation heat load and the fans are in operation. In this example, the minimum load corresponds to only about 30 percent of the capacity of the installed refrigeration plant. This minimum load factor will vary considerably with the type of store and mode of operation but some account may have to be taken of this difference between the maximum and minimum refrigeration requirements. If the store is operated with a number of compressors, they can be switched on and off as required. One large compressor may be fitted with off-loading equipment which allows it to work efficiently on partial loads. Other arrangements can be made to cater for the variation in refrigeration demand. What must not happen is that a large compressor should operate with a low load and hence operate with a very low suction pressure or stop and start too frequently. The first condition is bad for the compressor and the second for the electrical equipment.

Cold store capacity

There is no method of defining cold store capacity that satisfies the requirements of everyone concerned with cold storage.

Storage capacity based on the weight of produce that can be stored will depend on the storage density of the products and the method of storage. Therefore, unless only one product is stored under closely defined conditions, this definition is obviously unsuitable.

It is generally agreed that it is more appropriate to define storage capacity in terms of the store volume but there are a number of ways in expressing this value.

Gross volume is the volume of the refrigerated space.

Net volume is the volume that can potentially be used for storage and is the gross volume less the volume required for coolers, structural requirements, doorways and other permanent features of the store.

Effective volume is the store space that can actually be utilized for storage and it takes into account the requirements for passageways, stacking equipment, the bulk density of each product and the relationship between package dimensions and pallet dimensions, and pallet dimensions and the available space.

Gross volume and net volume can easily be defined by devising a simple set of rules for making these calculations. These store volumes, however, can only give a rough estimate of storage capacity and their main use may be for statistical purposes. The effective volume can only be calculated for each particular case and to make the calculation with any degree of accuracy, a drawing of the store layout would be required together with full details of the storage conditions. Store operators should therefore use general statements of store capacity with care and when ordering a store, they would give full details of the products and the storage operation to enable the supplier to provide a store to suit the operating requirements with the maximum utilization of the gross storage volume.

Ordering cold stores

Much of the details required to be supplied by the potential buyer of a cold store is similar to that given for a freezing plant and the list given at the end of Chapter 2 should be referred to. Additional information is required however for cold store installations and the following check list should also be used:

Storage capacity in t
Stowage rate of products in t/m^3
Operating temperature of store
Maximum ambient temperature and humidity
Temperature control range desired
Sketch of layout showing adjacent buildings
Maximum stacking height of produce
Method of storing produce with details of package and pallet dimensions together with accessibility required
Maximum floor loading due to produce and handling equipment
Type of handling equipment
Antifrostheave precautions required
Vapour seal and method of application
Maximum average temperature of produce when loaded
Weight of produce loaded per 24 h
Likely store utilization (number of times door is opened per 24 h)
Type of insulation preferred
Will store be built on the site or be erected from prefabricated panels
Method of cooling preferred
Refrigeration standby arrangement required

In addition to the above list and the list in Chapter 2, other requirements may be mentioned which the purchaser may think relevant.

No detail is too small to assist the supplier to provide a store to suit the purchaser's exact requirements.

6. WEIGHT LOSS FROM FISH DURING FREEZING AND COLD STORAGE

A good deal of confusion is created by the claims made in commercial catalogues for weight lost by fish during freezing. There is no intention to mislead the reader but unfavourable comparisons are made between one freezer and another, and these are often used to represent the general case.

Freezer weight loss

Weight may be lost by dehydration or due to physical damage of the fish during the freezing process.

Physical damage may be due to agitation during freezing which results in small pieces being broken off; this is likely, for instance, in freezers where the product is fluidized by the cooling air.

The other form of physical damage encountered during the freezing process is due to fish adhering to trays or conveyor belts. If the weight loss on releasing fish from trays is excessive, the trays may require to be sprayed on the underside with water. Fish frozen in continuous freezers with stainless steel link or mesh belts may suffer weight losses due to small particles being trapped in the belt.

Losses due to physical damage in a freezer should be small and need not be more than about 1 percent if the correct freezer and freezing process is being used.

Weight loss due to dehydration in a freezer depends on a number of factors, and the weight losses in air blast freezers give rise to the greatest controversy.

Weight loss due to dehydration will depend on:

Type of freezer
Freezing time
Type of product
Shape and size of product
Air velocity
Freezer operating conditions

Freezers such as plate freezers where the fish is frozen by contact and released by defrosting will have a negligible weight loss during freezing. Any measured change in weight will probably be due to loss of drip before the freezing started.

Dehydration losses occur mainly in air blast freezers and in other freezers which use a gas such as nitrogen or carbon dioxide in direct contact with the product.

The loss of weight in nitrogen, carbon dioxide and other cryogenic freezers will be low by virtue of the fact that freezing times are short. A direct contrast made between a carbon dioxide freezer and an air blast freezer showed that the weight lost from haddock fillets in the carbon dioxide freezer was about half of the weight lost in the air blast freezer, 0.6 percent compared with 1.2 percent. Other cryogenic freezers are likely to give rise to weight losses which are about the same as that of the carbon dioxide freezer.

Time in a freezer, however, cannot be directly related to the weight loss since the rate of weight loss shown in Fig. 50 is not directly proportional to time. More weight is lost at the start of a freeze than at the end.

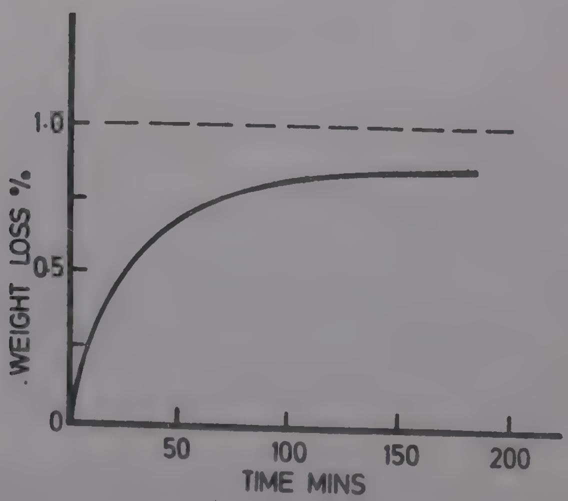

Fig. 50 Variation in the rate of weight loss from fish during freezing

The percentage weight loss from small fish will be higher than that for large fish. The rate of weight loss is proportional to the exposed surface area, and smaller fish have a greater surface area to weight ratio than larger fish. Fish frozen individually will lose more weight than fish frozen in a block, again because there is a higher surface area exposed. Wrapping fish during freezing will greatly reduce the weight loss but if the wrapper is loose, then weight may still be lost from the surface of the fish but retained in the package. The package will have the same total weight but the consumer cannot utilize the separated water.

Some weight losses are given in Table 8. The differences between different types of freezer are not great and not as high as some commercial literature would imply. It should also be remembered that some of the weight loss is due to the evaporation of surface water probably left from washing the fish, and this would have eventually been lost as drip if the fish had remained unfrozen.

One fact that is seldom considered is that fish kept in ice for a number of days will generally lose more weight than is ever likely in a freezer.

Table 8

Weight lost from fish during freezing

Product	Method of freezing	Percentage weight loss
IQF shrimp	Air blast	2 to 2.5
IQF haddock	Air blast	1.2
IQF haddock	Carbon dioxide freezer	0.6
IQF products	Liquid nitrogen freezer	0.3 to 0.8
Tray of fillets	Air blast	1.0
Large fish or blocks	Air blast	0.5
Blocks of fish	Contact freezer (metal to fish contact)	0
Cartons of fish	Contact freezer	0.5 within pack

In view of the weight losses quoted above, claims that fish may show signs of "freezer burn" or severe dehydration as the result of the freezing process would appear to be unfounded. The shape of the weight loss curve shown in Fig. 50 would imply that freezing times would have to extend to many hours or even days for "freezer burn" to become apparent.

Cold store weight loss

Much has yet to be done to correlate the rate of weight loss with differences between storage conditions but the rate of weight loss has been shown to vary with the following:

Temperature
Temperature fluctuation
Humidity
Heat transfer
Air flow over the product
Radiation effects of lighting
The product
Shape and size of the product
Type of wrapper

Most codes of practice only state the temperature for storage. Variations in the other factors that control the rate of dehydration can therefore result in cold stores having widely different storage conditions. The rate at which the product loses weight by dehydration can therefore vary considerably.

Table 9 shows rates of weight loss measured in a variety of stores. The losses are expressed as the weight changes per square metre of exposed fish surface. These results clearly show that there are great differences between the quality of cold stores which may be attributed both to their design and mode of operation as well as to the operating temperature. Apart from the physical loss in weight, excessive dehydration results in "freezer burn". The overall weight loss, however, cannot be used to define the point when "freezer burn" becomes apparent. Dehydration only occurs from exposed surfaces and the rate of dehydration is greater where the surface area to volume ratio is high. The edge of fish fillets and the corners of slabs of fish will therefore show signs of excessive dehydration or "freezer burn" long before the other exposed surfaces of the product. For this reason, "freezer burn" can even become apparent on glazed fish long before the overall weight loss is equal to the weight of glaze applied.

The rate of weight loss within a store can vary considerably with location. Fish stored near fan coolers, where they are subjected to high air velocities, will quickly show signs of dehydration. Fish stored against walls remote from the cooler may also suffer high losses due to poor air distribution and heat gains from the store walls.

Table 9

Rate of weight loss from fish in cold storage

Type of store	Average temperature (°C)	Rate of weight loss from exposed surfaces per day (g/m^2)
Jacketed	-29.2	0.17
Jacketed	-30.1	0.39
Jacketed	-30.2	0.60
Unit cooler	-29.3	4.96
Jacketed	-15.0	4.06
Pipe grid	-27.9	0.25
Unit cooler	-27.9	9.34
Finned pipe grid	-25.4	2.30
Unit cooler	-30.0	5.0 to 50.0

Note: The last store was a large store and the very high results were obtained in localities where unfrozen fish were placed in the store.

Fish adjacent to roof coolers may also dehydrate more quickly since the path of moisture migration is considerably shorter. Fish near the roof or walls of stores which are affected by a high incidence of solar radiation may also be subjected to higher losses.

Finally, fish in storage which have unfrozen or partially frozen fish frequently stacked alongside show the highest dehydration rates of all.

7. FINANCE OF FREEZING AND COLD STORAGE

Cost of freezing

An accurate cost can only be made for each individual case since so many factors have to be considered which depend on local conditions and economics.

This document can therefore only give the reader a guide to what differences in cost are likely to be between different systems. The information given will also help the reader by letting him know what costs must be considered to obtain the total cost of a project. Actual prices are given in the examples shown but they should not be used except as a very crude guide. The prices quoted are only valid for 1976 and are related to U.K. prices at that time. Differences between localities and widely changing values of currencies due to inflation and other factors may completely change the cost for individuals.

Small-scale operation usually means higher costs per kilogramme of product frozen. One manufacturer quotes a decrease in freezing cost per kilogramme of 40 percent in a plant with a capacity of 4 500 kg/h compared with one of 1 800 kg/h. Table 11 also shows how the capital cost related to the capacity decreases as the freezer size increases.

Table 10

Freezing cost for different freezing methods
(plant capacity 1 000 kg/h from +5 to -30°C)

Freezing method	Capital cost (U.S.$)	Total freezing cost (U.S. cents/kg)
Batch air blast freezer	120 000	3.0 to 4.0
Continuous air blast freezer	176 000	3.0 to 4.0
Horizontal plate freezer	100 000	2.2 to 3.3
Vertical plate freezer	105 000	2.2 to 3.3
Liquid nitrogen freezer	75 000	12 to 14
Liquid freezant freezer	160 000	about 6

Table 11

Cost of air blast freezers
(Blast freezer tunnel with trolleys)

Weight of fish frozen +5 to -30°C (kg/h)	Capital (U.S.$)	Capital cost (U.S.$/kg per h capacity)
25.0	6 200	248
45.0	8 200	182
90.0	14 200	157
190.0	30 000	157
500.0	69 000	138
900.0	105 000	116
1 400.0	158 000	112

The costs in Table 11 are ex-factory costs for freezer and refrigeration equipment only.

The costs do not include shipment, preparation of the site, supply of services or erection costs. Examination of Table 19 will show the wide variation in product heat load likely with changes in the initial temperature of the fish. This means that the cost of freezing will increase considerably in tropical countries if the fish are warm on loading the freezer.

Irregular and intermittent operation can also influence the cost of freezing. The more hours a freezer is operated and the more often it is operated at full capacity, the lower will be the cost per kilogramme of fish frozen. Freezers used during short seasonal fisheries for instance will have high freezing costs per kilogramme of fish frozen since all the fixed costs must be absorbed by a relatively small quantity of fish.

Freezing costs must also take into account other factors than direct money values. Product freezer losses can be significant especially if the product is highly priced. Losses can occur due to evaporation, mechanical damage which results in some of the product being rejected, and also mechanical damage which merely reduces the price obtained for the fish. A note on the likely losses in freezers is given in Chapter 2.

Other quality losses must also be taken into account if the freezing method is unsuitable or insufficient so that there are obvious quality defects. Drip loss, and loss in appearance or texture will lower the sale price and this may be attributed to freezing process.

Table 12

Cost of vertical plate freezers

Number of stations	Nominal capacity (kg/h)	Cost (U.S.$)	Cost rating (U.S.$/(kg/h))
12	135	7 600	56
20	225	10 400	46

Table 13

Cost of horizontal plate freezer

Number of stations	Plate area (m^2)	Nominal capacity (kg/h)	Cost (U.S.$)	Cost rating (U.S.$/(kg/h))
7	8.9	180	9 600	53
10	12.8	260	10 900	42
12	20.8	425	13 600	32
15	26.1	534	15 300	29

Table 14

Cost of horizontal plate freezers installed with refrigeration plant

Number of stations	Nominal capacity (kg/h)	Cost (U.S.$)	Cost rating (U.S.$/(kg/h))
7	180	18 400	101
9	232	26 400	114
11	386	31 100	80
15	534	36 000	67

The costs in Table 14 are those of the freezer and refrigeration plant. The cost includes transport to a U.K. site and the cost of installation but does not include preparation of the site, supply of services such as electricity and water, and the erection of buildings. Comparing the costs in Table 13 with those in Table 14 shows that the cost of the freezer is more than doubled if the costs of the refrigeration plant and erection are included.

Costing of freezing

Costing means a thorough investigation of all costs likely to be involved in the freezing process. This may be done to investigate the viability of a project at the design stage or it may be used to assist in budgeting and pricing of the product.

Many freezer operators may already have well established costing and budgeting systems and it is beyond the scope of this document to introduce or suggest systems that may be appropriate. However, guidance can be given on the particular considerations that have to be given to a freezing plant when a costing is made.

Costs are generally divided into three areas:

First costs
Annual fixed charges
Operating costs

The above costs areas can be further broken down into individual costs. The following list gives some guidance but individual circumstances may add to or substract from it:

First costs

Buildings
Land
Service charges for electricity, water, roads
Freezer plant
Delivery charges
Installation charges
Design and consultation charges
Refrigerant and oil charges

Annual fixed costs

Depreciation
Interest
Insurance
Taxes
Capital maintenance

Operating costs

Electricity - refrigeration plant, buildings, handling
Fuel - heating, electrical generator
Water - condensers, washing, glazing, general refrigerant
Oil
Labour - freezer operation, handling, supervision, office
Plant hire costs
Social dues

Costs should generally be calculated as the cost per unit weight (kilogramme or metric ton) of product frozen. This gives the real cost of the process and also takes into account the plant utilization factor which is extremely important.

Inquiries have shown that there are great differences between processors in the proportions of the total cost accounted for by each area of costing. Obvious differences such as the number of hours per year the freezer plant is operated can greatly change the cost pattern. The method of allocating capital costs to the freezing process can also vary widely especially when the building is used for other processes. One method used is to divide the cost on the basis of floor space occupied by the various processes but other methods may also be justified. One U.K. processor divides the freezing costs in the proportions stated below:

Preparation labour costs	48%
Packaging	10%
Freezing	10%
Overheads	32%

Another source quotes that about half the cost of air blast and plate freezing systems are accounted for by labour charges.

A worked example of the method of costing is given below for an air blast freezer freezing 900 kg/h. The prices are 1976 prices but the installation is fictitious and is only used to demonstrate the method of calculation.

	U.S.$	U.S.$
First cost		
Building and services	40 000	
Land	5 000	
Freezer plant	105 000	
	150 000	
Annual fixed charges		
Depreciation (10%)		15 000
Interest (12%)		18 000
Insurance and taxes (4%)		6 000
Capital maintenance (4%)		6 000
		45 000/year
Operating costs		
Power 60 kW for 2 000 h = 120 000 kWh add 15% for auxiliaries = 138 000 kWh 138 000 kWh at U.S.$ 0.04/kWh	5 520	
Water	1 000	
Labour 3 men for 2 000 h = 6 000 h 6 000 h at U.S.$ 4/h	24 000	
office work accountable to freezing	5 000	
Supplies Refrigerant, oil, packaging office supplies	2 000/year	
Summary of annual operating costs		
Power		5 520
Water		1 000
Labour		29 000
Supplies		2 000
		37 520
Total annual charges		
Fixed		45 000
Operating		37 520
Total charges		82 520

Fish frozen

900 kg/h for 2 000 h = 1 800 000 kg

Cost of freezing

$$\frac{82\ 520}{1\ 800\ 000} = \text{U.S.\$ } 0.045/\text{kg}$$

If the freezer was fully utilised for 3 000 h/year, the cost of freezing would be reduced to U.S.$ 0.037/kg.

Cold store costs

Cold store costs may be integrated with freezer costs if freezing and cold storage facilities are provided at the same time and used only by the owners. Cold stores operating as public stores and providing low temperature storage facilities for customers will have to be costed to determine the charge to be made and the profitability of the store.

It is particularly difficult to give the reader some guidance on the likely cost of a cold store since, unlike freezers, refrigeration costs are relatively small. The main costs are in the construction of the building, preparation of the site and provision of services. These costs will depend to a great extent on the location of the site. The reader may appreciate however some costs to indicate the likely sum involved in the construction of a cold store, and the figures given below in Table 15 are U.K. prices for 1976. The prices are for cold stores constructed from prefabricated panels and designed for operation at -30°C. The price includes buildings, land, engine room equipment, electrical installation and other services.

Table 15

Cold Store Costs

Size of store (m^3)	Cost (U.S.$/$m^3$)
500	121
1 000	113
10 000	100
40 000	80

Costing of cold storage

The method of costing cold stores will be similar to that used for freezers and the check list presented earlier in this chapter can be used as a guide.

An analysis of cold storage costs in the U.K. has shown wide variations in the distribution of costs depending on the function and method of operation. Such facts as whether the cold store is public or private, general purpose or special, used for distribution or for long term storage, influence the cost allocation and account for the range of costs shown within the brackets.

Survey of cold store costs

Administration

Clerical Order processing Invoicing Stock control Selling Management Postage Telephone	15% (13 to 42)

Handling

Labour and equipment Pallets Trucks	25% (23 to 32)

Storage

Site	
Buildings	60%
Refrigeration	(53 to 62)

(Maintenance, depreciation, taxes, water, electricity, refrigerant, etc.)

The preceding survey showed that utilization was an important factor, and utilization should be calculated on a volume basis in metric tons per cubic metre. This figure indicates not only the quantity in store but also relates to the bulk density and the space it occupies. The survey also showed that increased mechanization did not necessarily reduce the handling costs. About 50 percent of the handling cost was accounted for by equipment and, with public cold stores in particular, the cost of pallet losses can be high. This fact should not however detract from the importance of handling goods in and out of the store quickly and efficiently. Loss in product quality due to poor handling methods is also an important consideration.

Operating costs for a 10 000 m^3 cold store can be twice as much per cubic metre of storage space as those for a 100 000 m^3 store. The size of a cold store is therefore a very important factor in costing.

Private cold stores are also likely to have a lower level of occupancy than public cold stores since seasonal stock variations for different commodities are more likely to balance each other in a public cold store.

The following calculation is typical of the kind that would be made by a cold store operator who is hiring out low temperature storage space for already frozen produce. The calculation does not take into account transport costs outside the store since this is assumed to be the responsibility of the owner of the frozen goods.

Again it must be said that the prices and rates used are as accurate as they can be made for this type of operation and are applicable to U.K. practice in 1976. However, operators should substitute their own figures when making a similar calculation.

First costs

		U.S.$	U.S.$
Buildings, land, refrigeration equipment and services		113 000	
Additional handling equipment		20 000	
		133 000	

Annual fixed costs

Depreciation (10%)			13 300
Interest (12%)			15 960
Insurance and taxes (5%)			6 650
Capital maintenance (4%)			5 320
			41 230

Operating costs

Power	35 kW for 4 380 h = 153 300 kWh 153 300 kWh at U.S.$ 0.04	6 132	
Water		1 000	
Labour	2 men at U.S.$ 160/week	16 640	
	1 man at U.S.$ 200/week	10 400	
Supplies	oil, refrigerant, office supplies	2 000	

Summary of annual operating costs

Power	6 132
Water	1 000
Labour	27 040
Supplies	2 000
	36 172/year

Total annual charges

	U.S.$
Fixed	41 230
Operating	36 172
Total charges	77 402

Return on investment required = 20%

Annual profit required $\frac{20}{100}$ x 133 000 = 26 600

Cold store capacity: 500 t

Estimated utilization: 60%

Utilization = 500 x 0.6 x 365 = 109 500 t days

$$\text{Charge for storage} = \frac{77\ 402 + 26\ 600}{109\ 500} = \underline{0.95}\ \text{U.S.\$/t/day}$$

A similar calculation can be made for calculating the cost of hiring space within the store rather than on the basis of cost per unit weight of stored produce as shown above.

8. FREEZING AT SEA

Why freeze at sea?

The length of time a fishing boat can remain at sea depends on the time the fish can be kept so that they are still edible on reaching the consumer. Storage in ice or by other means which keep the fish chilled is adequate for periods not much in excess of two weeks. Fish such as haddock and cod caught in the North Atlantic fisheries can be stored for up to 15 days in ice and then they rapidly become inedible. It has been found that fish caught in tropical water can remain edible for even longer periods when stored at chill temperatures. This may not be a general rule and the limitation of chilled storage must be established by local experience.

In practice, the time restriction for storage in ice often means that fishing vessels must return to their home port with the fish room partly empty. There is therefore a need for some means of preservation that will extend the storage life without substantially altering the nature of the raw material. Quick freezing and cold storage is an excellent way of doing this.

When newly caught, fish are frozen quickly and stored at a low temperature on board, there is then no limit imposed on the length of voyage due to spoilage of the catch. Fishing vessels can remain at the fishing grounds until the hold is full. This effectively increases the proportion of time spent at the fishing ground and thereby improves the economics of fishing. Freezing at sea also improves the general quality of the fish landed. It also allows the fish to be distributed to a wider market even without the existence of an elaborate "cold chain". Fish which have been frozen at sea are of very good quality when landed; therefore, more time is available for the fish to be distributed over a wider area and still be in good condition.

Freezing at sea has therefore an important role in world fisheries. A look at a map will show that large areas of ocean are far distant from any centres of population or even land, and many potential fisheries are therefore unexploitable without a method of preserving the fish for long periods. Only quick freezing and low temperature storage has so far satisfied this need and, as traditional near water fisheries become overfished or are unable to satisfy the growing demands of an ever increasing population, freezing at sea will become more and more necessary.

Type of freezer vessel

Fish frozen at sea may be frozen whole immediately after catching and, when thawed on shore, can then be used in much the same way as newly caught fish or fish traditionally preserved in ice. Alternatively, the fishing vessel can operate as a fish processing factory and the fish may then be filleted, packaged and frozen, and the waste products converted to fish meal and oil.

Freezing of the whole fish has the following advantages over processing before freezing. The number of crew required is not much greater than for a fishing vessel of comparable size preserving its catch in ice. Processing equipment and hence, factory deck space, is a good deal less. The whole fish, when thawed after landing, are available for any form of traditional processing. The problems associated with freezing newly killed fish are a good deal fewer with whole fish than with fillets. For the above reasons, it may therefore be advisable as a first step for a developing country to freeze whole fish and progress to a factory-freezer operation as the situation demands.

How good are sea-frozen fish?

Sea-frozen fish, prepared from fresh raw material and properly handled between landing on deck and loading into the freezer, can be virtually undistinguishable when thawed from fresh fish and the quality may be considerably better than fish kept in ice for more than a few days.

The loss in quality as a result of freezing, cold storage and thawing is insignificant when these treatments are properly applied. Thus, when very fresh fish are frozen at sea, the final product can be equal to the best on the market.

Freezers for use at sea

A number of conventional freezers may be used at sea with little modification. The freezer and its refrigeration system, however, have to conform with national regulations and insurance requirements for fishing vessels. Many countries, for instance, do not allow the use of ammonia as a refrigerant because of its toxicity and because there is a potential explosion hazard. The design and operation of the freezers and the refrigeration system must take into account the movement of the vessel, vibration, sea-water corrosion and the extra rough usage likely under the arduous conditions experienced at sea. Another factor that may influence the choice of type of freezer is the type and variety of fish species to be frozen. In fisheries where a large number of fish species are normally caught, the freezer should be able to cope with this variation in requirements.

The VPF was specially designed for freezing whole fish at sea. In most applications, a 1 mm spacing between plates was found to be adequate. This spacing accommodated a very high percentage of the catch with only a few oversize fish being rejected. These oversized fish were normally frozen in a separate air blast freezer room. The 100 mm spacing also allowed the fish to be quick-frozen and reduced to the cold storage temperature of -30°C in the recommended time of 4 h.

The U.K. design considerations which led to a 100 mm spacing being used were based on the freezing of gutted fish with heads on. Other countries' requirements may be for ungutted fish to be frozen or for fish to have the heads removed as well as guts before freezing. These considerations will have to be taken into account as well as the size, shape and variety of species to be frozen before a decision is made on the preferred plate spacing.

Another factor to be taken into account with any type of freezer is the overall size and weight of the frozen product. If the product has to be lifted and stacked in the cold store of a fishing vessel, care should be taken that it is well within the physical capabilities of the crew. Since there are great differences in stature between different nationalities, maximum block size and weight cannot be rigidly defined. It has been possible, however, to operate in the U.K. with 45 to 50 kg blocks measuring approximately 945 x 475 mm.

Many other types of freezer are also suitable for freezing fish at sea, and HPF, brine freezers and a variety of air blast freezers have been used for this purpose. Most of these freezers have been described in Chapter 2 but for use at sea they have to satisfy some special requirements.

The following design and operational requirements for freezers to be used at sea will give the reader guidance on whether a freezer is suitable for this application:

(1) The freezer should be easily loaded and unloaded.

(2) Freezers with trolleys should have special arrangements to make them safe during rough weather.

(3) The freezer should be able to retain the product during the loading and unloading procedures; serious damage or injury can result from a dislodged frozen block or tray of fish.

(4) The freezer should be able to operate with part loads which may result from variations in the catching rate.

(5) The refrigeration system should not give rise to uneven freezing due to displacement of the refrigerant with the movement of the vessel.

(6) The freezer should be robust.

(7) The material used in the construction of the freezer should be resistant to seawater corrosion.

(8) The freezer should be constructed so that it can be cleaned by hosing with seawater.

The above list is not exhaustive but it is sufficient to indicate that many types of freezer would, in fact, be unsuitable for use on a fishing vessel.

Space on a fishing vessel is limited especially in the height available between decks. Freezer designs and layout should therefore be made to suit this space restriction. The quicker the freeze, the smaller is the size of a freezer for a given capacity. Freezers for use at sea should therefore operate under conditions that result in short freezing times. This requirement relates to both the refrigerant operating conditions and the product shape and size. Large fish like tuna, however, are frozen individually. Brine immersion freezers have been used but there has been a recent trend toward air blast freezers for this purpose. Shell-on shrimp and other shellfish are also frozen individually, but apart from these few exceptions, freezers for IQF products are unlikely to be required on a fishing vessel.

Extra care has to be taken with the refrigeration equipment. Pipework should be made secure and routed so that it is unlikely to be damaged. The need for a system that can be maintained in a relatively leak-free condition has resulted in the use of secondary refrigerants for many shipboard systems. When a secondary refrigerant is used, the primary refrigerant is confined to the limited area taken up by the condensing unit and heat exchanger. Since secondary refrigerants are liquids which only operate at pressures which depend on the pumping requirement and are liquids at atmospheric pressure, there will be a greatly reduced incidence of refrigerant leaks. Calcium chloride brine and trichloroethylene have both been used for this purpose. The major requirement for both the freezer and the refrigeration system on a fishing vessel is reliability. The economy and savings applied to a shore-based installation can be quickly lost if a vessel is laid up for even a short time.

Handling fish before freezing

The layout of a stern trawler provides for a good arrangement for handling fish before freezing. The fish are pulled up the stern ramp, poured from the net through hatches to the factory deck below and then moved forward as they go through the various stages of processing. Obviously, with many types of vessel this preferred arrangement cannot be achieved and it would be impossible to cover all the potential layouts for the wide variety of vessels now used for freezing at sea.

The pre-freezing procedures described below are typical of a freezer trawler fishing the North Atlantic. They may, however, have a more general application, and only minor modifications may be necessary to accommodate other vessels and their particular requirements. Fish are not left lying on the upper deck exposed to direct sunlight but stored on a sheltered working deck immediately below. Ideally, the fish should be kept as cool as possible immediately after catching and throughout the time they are awaiting freezing. Some means of chilling, such as a spray of seawater, is therefore recommended when the fish are subject to any delay before gutting. This cooling of the fish not only helps to retard spoilage but also stops the blood from clotting too quickly. In tropical conditions, it will be necessary to provide a means of chilling the water used for this purpose.

Gutting of fish should commence as soon as possible not only to ensure the continuity of supply to the freezers, but also to reduce the rate of spoilage. There are several important reasons why fish should be gutted as soon as possible after they are caught. First, the removal of the gut reduces spoilage brought about by digestive juices in the gut attacking the belly wall. Many of the spoilage bacteria present are in the guts of the fish and if the fish are quickly gutted and thoroughly washed, bacterial spoilage will be reduced. Secondly, efficient gutting also releases the blood from the fish. When this blood is not released soon enough, or not at all, it clots within the tissues resulting in a permanent pink or red discoloration of the flesh. This will detract from the appearance of the fillet. Thirdly, the liver is removed. The liver contains a fat which is highly perishable and could become rancid even at low temperatures. Finally, if the gut is not removed and the fish washed, the contents of the gut could contaminate the fish at some later stage of processing. Traditionally, some fish may only be marketable complete with guts and in these cases a special effort should be made to handle the fish quickly. They should be kept chilled and rough handling should be avoided.

Fish are usually sorted before freezing so that each block or package contains only one species. With some species, further subdivision into size grades may also be necessary. This extra handling for sorting and grading is economically viable when a premium price is paid for graded fish. Some sorting

is required before processing to reject unwanted and undersize fish and any trash material. Whether it is also feasible at this time to sort the fish to be frozen into species and size grades will depend on individual requirements.

Heading of the fish may be desirable in some cases. Headed fish make a more compact block and larger fish may be frozen in some freezers than would otherwise be possible with heads on. Removing the heads also means that the freezers can be used more efficiently and the stowage rate of edible fish in the cold store is also increased. One disadvantage of heading is that a small but not insignificant amount of edible fish is removed with the head. The cut surfaces may also become discoloured in time and trimming may be necessary.

After gutting and heading, the fish are thoroughly washed in cool, clean water to remove most of the remaining dirt and bacteria, and also to wash away the blood that is released. The fish must remain in the water long enough to bleed properly. If they continue to bleed after removal from the washer, unsightly clots of blood may form on the fish while they are waiting to be frozen. A time of 15 to 30 min in cold water is usally required for bleeding to be complete. However, in practice it is often difficult to ensure that all fish are given time to bleed properly. One solution is to make washing a two stage process. The gutted fish are first put into an open tank where they can bleed while they are kept cool by chilled water sprays, and then they are conveyed to an automatic fish washer where they are given a final rinse before freezing. The need for delay for proper bleeding of the fish before freezing must seem an added encumbrance. However, where it is desirable to gut before freezing, time must be allowed for the blood to be released from the fish to ensure they have a good appearance. If appearance is not important in the final product, this delay for bleeding may not be necessary.

Small pelagic fish such as herring are traditionally landed in the whole ungutted state and, when freezing species such as these, freezing is done as quickly as possible. The fish should also be kept cool since spoilage rate will be higher than for larger fish that have been gutted.

Another major problem, which usually only applies when fish are frozen at sea, is due to the effects of rigor mortis. Rigor mortis or death stiffening is the physical change that occurs in all animals including fish as a result of a series of complex reactions that go on in the flesh tissue after death. It is characterized by a gradual hardening or stiffening of the carcass brought about by a stepwise contraction of individual muscles. Once stiffening is complete, that is when all the muscles have contracted as far as they are able, the carcass will remain stiff for a considerable time after which the muscles will relax gradually and the carcass will become limp or flaccid.

Very often when fish go into rigor, they do so in a bent condition. This should be avoided as far as possible since the flesh of the fish on the outside of the curve will be put under a strain and, when rigor sets in, the extra forces involved will pull the fish apart. This results in gaping of the fillets. The fillet on the inside of the curve, on the other hand, will shrink and contract so that two different looking fillets will be obtained from the same fish. One will be elongated with much gaping and the other will be short and compact. Freezing will of course maintain the fish in this bent condition, and will no doubt be blamed for the phenomenon. If bent fish in rigor are straightened before freezing, gaping of the short compact fillet will result. The onset of rigor mortis is quicker at higher temperatures and may occur only 10 to 20 min after death at temperatures near 30°C. It is therefore essential that the fish be chilled quickly if problems due to rigor mortis are to be avoided during freezing.

If the fish are to be filleted at sea and frozen as fillets, it is even more important that chilled conditions exist along the entire production line. The reason for this chilling requirement is that, when a fish goes into rigor, there is a gradual increase in the tension of the muscle fibres and, as long as the muscle remains attached to the skeleton of the fish, shrinkage is restricted. However, once a fillet is cut from the fish, this restraint is removed and, if the onset of rigor mortis is not complete, the fillet will shrink. This contraction gives the fillet a corrugated appearance and a distorted shape. Temperature has an important bearing on this process. The higher the temperature, the faster the shrinkage and hence, the greater the effect in a given time. Fillets that are allowed to shrink at a high temperature before freezing can lose greater quantities of drip on thawing. In addition, excessive flexing or contact with water can increase the amount of shrinkage of a pre-rigor cut fillet.

A fillet taken from a fish before rigor has set in will, after freezing and thawing, have a dull appearance. This absence of gloss is probably due to the cut ends of muscle cells projecting upward. The fillet has a velvety feel and will not, for instance, produce an attractive smoked product. There is no known solution to this problem so far apart from delaying filleting until after the onset of rigor mortis.

Before freezing, the fish may be stored in bins of a predetermined volume adjacent to the freezers. This ensures that only the correct quantity of fish is available to fill the freezers and none are left on conveyors. The working space adjacent to the freezers should be kept cool to ensure that the fish do

not warm up at this stage and the bins should be emptied in strict rotation so that no fish lie longer than necessary. A final sorting check can be made at the freezer and some facility should be provided for the storage or return of rejects.

It must be remembered that any chilling of the fish prior to freezing is not an extra refrigeration requirement since any heat removed before entering the freezer means a reduction in the freezer refrigeration loading. Chilling therefore can be a low cost process with considerable benefits in improved fish quality.

Handling frozen fish

Fish should be transferred to the cold store immediately when they are removed from the freezer. Even large blocks of fish warm up rapidly at ambient temperatures particularly in tropical climates. Heat added to the fish at this stage means that it has to be removed in the cold store and this will mean some loss in quality. Wherever mechanical aids, such as chutes or conveyors, are provided, they should be used since the less handling the frozen fish receives, the less chance there will be of the fish being broken or damaged. Broken or damaged blocks mean that more storage space is required in the cold store and a great deal more handling is also required. Broken and damaged fish should be kept separate in the store so that they can be handled separately at the time of discharge since this may require special arrangements.

Never put unfrozen or partially frozen fish in the cold store. The cold store is not designed to freeze and apart from doing this badly, the extra refrigeration load will result in a rise in the temperature of the store. Partially frozen fish are also more easily damaged during handling and this will mean even more damaged blocks and broken fish. When fish are graded before freezing, the blocks or packages should be clearly labelled and, if possible, the different grades should be kept separate within the cold store. Labels placed on the surface of frozen fish and brushed over with clean water will adhere to the surface and this method of marking can be used if the fish are unwrapped. If wrappers are used for the fish, they should be suitable for marking so that the fish can be identified. Marking the fish clearly will allow the fish to be handled more quickly at the time of discharge or at any other time when the fish have to be identified and sorted.

Cold stores on freezer vessels

The cold store on a fishing vessel should operate at the temperature recommended for shore based cold store practice. Even if the storage time on the vessel is to be relatively short, it must be remembered that any practice that is less than ideal at each stage of handling and processing will have a cumulative effect which may become obvious by the time the fish reaches the consumer.

The general principles for store design and operation apply to cold stores on fishing vessels, and the chapter dealing with this subject should be referred to.

Loading and unloading of a fishing vessel's cold store is usually done through hatches at roof level. This arrangement is a good one since there will be little exchange of air between the store and outside when the hatches are open. The cold and therefore denser air in the store will not flow upward and be replaced by warm air. One distinct disadvantage of this hold arrangement is that even small refrigerant leaks can result in an accumulation of refrigerant in the cold store and, although the refrigerant may not be toxic, the resulting low oxygen level may be dangerous. Shipboard cold stores should therefore have an effective alarm system and the crew should be disciplined to use it and obey all other safety rules and regulations.

Frozen fish in the cold store of a fishing vessel may have to be stacked with a retaining system to prevent movement of the product. A structure similar to that used to form partitions and shelves in the fish room of a wet fish trawler has been used for this purpose.

The following figures should only be used as a rough guide since the finer details of store construction and layout, the shape and size of the frozen product, and the method of packing can mean considerable differences in storage densities for apparently similar installations.

Table 16

Stowage rates for frozen fish in the cold store of freezer vessels

	(m^3/t)
Large blocks of cod (including allowance for support structure)	2.0
Large blocks of cod (open stowage with no support structure)	1.4 to 1.7
Large blocks of fillets (including allowance for support structure)	1.2 to 1.5
Frozen cod stowed as single fish	2.2 to 2.6

Insulation of a cold store on board a fishing vessel creates some special problems. The cold store insulation is usually attached directly to the ship's side; therefore, the rib structure of the vessel will penetrate into the insulation for some distance. Although the thickness of the insulation need not be increased to more than would be necessary for corresponding store on shore, the design should ensure that there is an effective thickness of insulation at all points in the store (Fig. 51). Any internal structure within the cold store space should be attached to the main framework of the vessel with an effective heat barrier. Metal or any other material with a high thermal conductivity should not be used for this purpose.

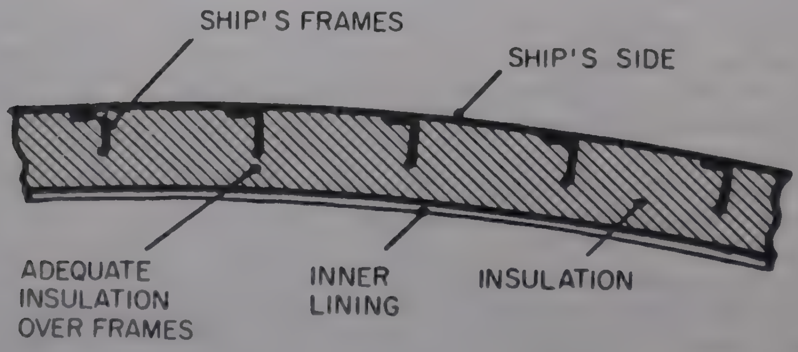

Fig. 51 Insulation of a fishing vessel cold store

Foamed-in-place polyurethane insulation has been used for the insulation of shipboard cold stores. The application of this type of insulation is difficult and requires skilled operators and special equipment. Polyurethane slabs and other insulation materials have been used but strict regulations about the fireproofing requirements for shipboard insulation have now considerably reduced the choice. Loose and blanket insulations by themselves are not suitable for this type of cold store since the movement of the vessel would quickly settle the insulation and leave uninsulated areas behind the cold store lining. In addition, the thermal resistance of this type of insulation is not particularly high and the greater thickness of insulation that would be necessary would be wasteful of space. Increased insulation thickness can be costly on a fishing vessel since only a few centimetres increase in thickness can mean a significant reduction in the storage space. A store holding about 100 t of fish, for instance, would be reduced to about 95 t if the insulation thickness is increased by only 5 cm. Loose fill insulation may however be used in combination with others for instance for packing awkwardly-shaped areas where cutting of slabs would be difficult. Another desirable property of an insulation for a steel fishing vessel is that it should be reasonably heat-resistant to enable welding or other heat treatment to be made to the outer hull.

Unfortunately, none of the insulations that are likely to be used can completely satisfy all the requirements but some are significantly better than others.

Insulation choice and method of application can only be made after consulting the relevant codes of practice or legislation for shipboard insulation for the country in which the vessel is registered or insured.

The choice of cooling systems available for the cold stores of fishing vessels is much the same as that for other stores. Pipe grids, forced circulation coolers and some semi-jacketed arrangements have all been used successfully. When large blocks of fish are stored, the system selected should not be vulnerable to damage due to block handling or movement. Grids on the sides of the vessel require to be protected since a 45 kg block of fish can damage pipework particularly since metal is a good deal more brittle at cold store temperature. Plain pipe grids on the roof only have been used but, in order to get the required heat transfer surface, finned grids are usually required and care must be taken to ensure that the frost on the pipes does not bridge the air space between the fins. If plain pipe grids are used, it will normally be necessary to continue the grids to at least halfway down the sides of the hold.

Attempts have been made to avoid using wall grids by having two or more rows of plain pipe grids on the roof. In terms of cold store quality, this is an inferior arrangement and also makes defrosting more difficult than when a single row only is used. Cooling grids together with any protective lining take up a good deal of space in a store but, since it is advisable in good storage practice not to stack produce directly against the insulation, not all of the grid space will be additional to this requirement.

Whatever system is used, the insulation and the cooling grids must be protected from damage by the fish and fish handling equipment within the storage space. As in some modern stores on shore, unit coolers may be used and they can be located outside the main storage area and the cold air circulated within the room. Arrangements should be made for distributing this air uniformly. This system has been used at sea and, as in a shore-based store, the compact cooler requires frequent defrosting.

Unloading freezer vessels

Frozen fish is obviously a different product to handle than iced fish and cannot therefore be unloaded in the same manner. The prime requirement of an unloading system is that the fish should be handled quickly between the vessel's cold store and the cold store on shore. Delays at this stage particularly in warm climates can result in partial thawing of the fish with a resultant loss in product quality.

There should be no delays on the quayside, and any grading of the frozen fish according to species or size would be left until the produce is in the cold store or at least under cover. Ideally, cold stores should be adjacent to the landing place and fish can then be moved quickly probably by conveyor into cold storage. If this arrangement is not possible, but the store is reasonably near to the quay, unrefrigerated vehicles may be used for transporting the fish provided there are no delays. Vehicles, however, should be of the enclosed type and they should be loaded under a canopy so that fish are not exposed to direct sunlight. The capacity of vehicles should not be overlarge since if a long time is taken to complete a load, a good deal of heat can be added to the fish. Even when smaller vehicles are used if there are delays, the vehicle should be dispatched to the cold store with a partial load rather than wait to be fully loaded. In some countries, labour may be relatively cheap and mechanical handling may be considered an expensive luxury. In these cases, it may therefore be more economic and even desirable to manhandle the fish during unloading. However, if this means long delays and results in partial thawing of the fish, a quick handling method should be used. The rate of unloading of frozen fish from a vessel will depend on the size of blocks or packages or the containers used for loose fish. It will also depend on the facilities provided on the vessel, such as number and size of hatches, and also the degree of accessibility and hence the number of men that can be employed at one time. With a mechanical unloading system, unloading rates of 1 to 1.5 t/man hour can be achieved with unloading crews familiar with the method. Mobile cranes and ship's derricks have also been used to unload frozen fish. With these methods, the fish are loaded onto enclosed containers in the hold, lifted through the hatch and transferred to the quayside. This operation should ensure that there is no delay on the quayside in order to transfer and sort fish. Storing the fish in containers in the ship's hold has been suggested but unless the vessel is specially designed for this purpose, up to 30 percent of the available storage space could be lost due to the presence of the pallets and the need for squaring off the hold. This would mean that a fishhold capable of storing 600 t of unpalleted frozen fish in open storage would only be able to hold 400 t if the fish were graded and stored in containers. Only if a freezer vessel reached the proportions of a cargo ship would palletisation be achieved without a significant loss since a vessel of that size would have parallel sides for a good length of the hold. The stowage rates given in Table 16 give some guidance for calculating the likely hold capacity.

9. TRANSPORT OF FROZEN FISH

Frozen fish delivered to a destination where they are to be sold immediately are likely to be eaten within a few hours and no harm is done if they are partially thawed on arrival at their destination. The frozen fish may in fact be carried in uninsulated containers depending on how long the journey takes. Enclosed vehicles, however, should be used or at least a cover provided to protect the fish from direct sunlight.

If the journey is longer, an insulated vehicle will be required so that the fish especially on the outside of the load do not get overheated on the way. Transit by this method may be suitable for quite long journeys depending on the initial temperature of the fish whether the vehicle is fully or partly loaded, the size of the load, the insulation quality and thickness, the degree of air ingress and the local climatic conditions. Journeys of perhaps 500 to 1 000 km may be possible with this means of transportation but only local trial will ascertain the maximum attainable.

Frozen fish that are to be transferred to other cold stores must be transported in an insulated vehicle preferably with some form of refrigeration equipment to maintain the air space at a temperature of approximately -20°C.

The use of mechanical refrigeration units is the most widely used system for refrigerating the vehicle storage space but the following list also names other methods that may be used:

(1) Mechanical refrigeration using either wall coolers or forced convection coolers blowing air throughout the storage space. In some cases, a jacketed system for distributing the air is employed.

(2) Rechargeable eutectic plates.

(3) Solid or liquid carbon dioxide or liquid nitrogen can be used with a total loss system.

The cost of a vehicle complete with a mechanical refrigeration system suitable for maintaining a temperature of -20°C would be approximately U.S.$ 42 000. This vehicle would be suitable for transporting 15 t of frozen produce. The price is the 1976 figure for delivery to a U.K. port.

Prior to loading, the vehicle or container should be precooled and the loading should proceed quickly. Palletized loading and the formation of a sealed connexion between the vehicle and cold store are both helpful in keeping the temperature rise at this stage to a minimum. The size of a package affects the speed at which it warms; the smaller the pack the greater is its surface area in relation to its volume and the quicker it warms. Fig. 52 shows laboratory measurements made on a single consumer pack and on a carton of the same packs. Packaging the product in a master carton will clearly reduce the temperature rise during handling outside a refrigerated space.

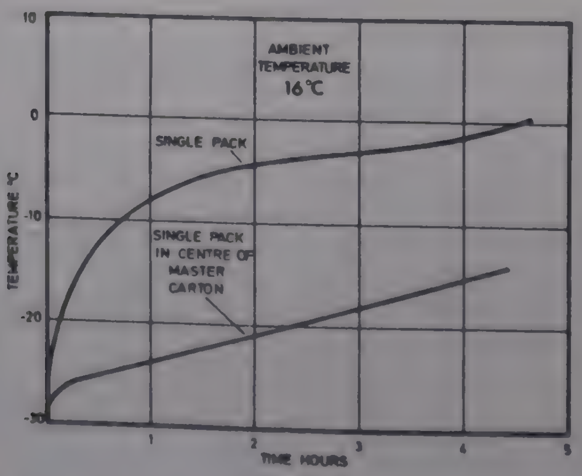

Fig. 52 Comparison between the rates at which fish in single packs and cartons warm up

Fish at the edges and corners of the load will warm much more than those at the centre of the load during unrefrigerated transport, and the extent of this temperature difference is not often appreciated by the operator. Fig. 53 shows the result of temperature measurements made across the middle of a load in an uninsulated container. The temperature rise was almost entirely in the outer 300 mm layer of the load which in this case was packed firmly against the container wall without an airspace. It must be remembered that the outer 300 mm layer represents a considerable part of the total load. For example, in a container measuring 5 x 2 x 2 m almost 60 percent of the load would be located within 300 mm of the wall.

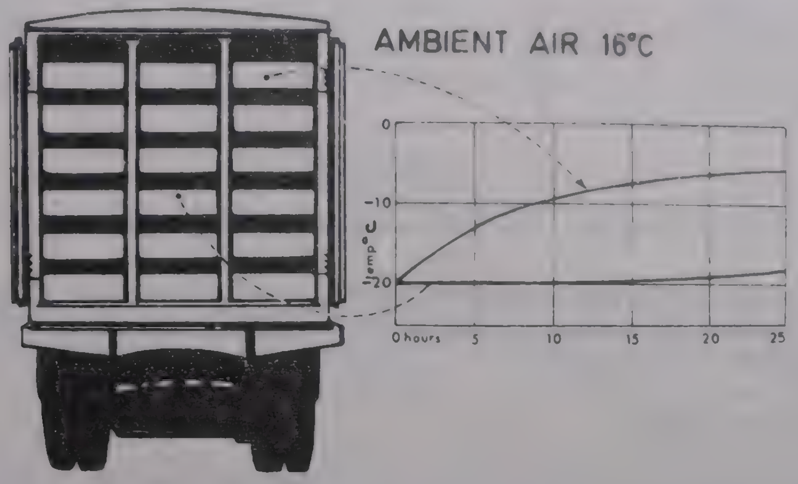

Fig. 53 The effect of position in the load on the temperature of frozen produce in an unrefrigerated and uninsulated vehicle

The above temperature measurements made during the transport of frozen fish were made in a temperate climate when the ambient temperature was about 16°C. The results clearly show the effects of bulk, size and position in a load on the rate of warming when no refrigeration is used. The differences will be even greater in warmer climates.

10. REFRIGERATION PLANT REQUIREMENTS

Most of the mechanical refrigeration plant used for freezing and cold storage of fish is of the vapour compression type basically consisting of compressor, condenser, expansion valve and evaporator (cooler).

In simple terms, a refrigeration system takes in heat at a low temperature and rejects it at a higher temperature.

Compressors

The selection of a compressor to suit a particular installation will depend on the particular requirements of that installation, and this job is better left to a qualified person. Detailed information on compressor design cannot be given in a document such as this.

As a general rule, freezers and cold stores should not share the same refrigeration machinery. Load fluctuations brought about by the freezer being loaded and unloaded will result in temperature fluctuations within the cold storage space. In addition, when the cold store only is in operation, a refrigeration compressor of large capacity will be used for what is a relatively small refrigeration load. Apart from being uneconomic, this will result in problems with capacity control. The exception to this general rule for not sharing compressors is a very large installation with a multiple compressor system and a competent engineer in charge.

Condensers

Table 17 gives some indication of the water requirement for various types of condenser.

Table 17

Condenser water requirement
(t/h)

Type of condenser	100 kg/h freezer	1 000 m^3 cold store
Shell and tube (water rejected)	5 to 7	10 to 14
Shell and tube with water recooling	0.03 to 0.06	0.06 to 0.12
Evaporative	0.03 to 0.06	0.06 to 0.12

Selection of a condenser must take into consideration many factors relating both to the system used and to the climatic conditions. Selection must again be left to a qualified person who is aware of all the relevant information about the project.

General notes on refrigeration plant

Duplication of cold store plant. The value of frozen product in a cold store can be high and precautions must be taken to ensure that the contents are not damaged in the event of a major breakdown of the plant. Cooling by multiple units, each with a separate condensing unit, is one way of ensuring that at least sufficient refrigeration effect is available to maintain the store at the operating temperature or slightly higher if a unit should break down. Another method is to cross-connect the cold store and freezer refrigeration pipework. This allows the freezer refrigeration machinery to be used to cool the store in an emergency. With normal operation, the two would be isolated and only a competent person would be allowed to make the cross-connexion.

Centralized plant. A good policy to follow is to centralize machinery so that one operator can take care of all the refrigeration equipment. Care should be taken however that the refrigeration lines to and from the cooler are not too long. Long refrigeration supply pipes give rise to a number of difficulties. Care should therefore be taken in arranging plant layout. Plant operation and economics are considerations that also have to be taken into account.

Standardization of plant. Standardization of equipment is another good policy to follow especially in remote areas. Parts can be interchanged and stocks of spares will be kept low. If possible, the same refrigerant should be selected for each installation and similar machinery made by one manufacturer should be specified. The size of individual units should also be standardized whenever possible even if it means that some adjustment has to be made in their capacity to suit each requirement.

Simplicity and reliability. Small plants seldom justify a full time engineer in attendance; therefore, simplicity and reliability should be major considerations when selecting the equipment particularly in a developing country. The plant and all auxiliaries should also be well tried and tested. Although these requirements apply particularly when plant is unattended, conditions in most developing countries are such that they should be applied there as a general rule. Whatever incentive there may be to purchase plant that is new and offers potential economic or other benefits, the purchaser should place a good deal of importance on reliability.

Instrumentation. All refrigeration plant should be well instrumented.

Good instrumentation helps the operator to spot faults before they become serious and also helps to identify them so that maintenance time and costs can be kept low.

Power requirements

The electrical power required for the operation of a refrigeration plant depends on many factors and general figures are seldom quoted.

The lower the temperature at the cooler and the higher the temperature at the condenser, the more energy is required to transfer a given quantity of heat. This is shown in Table 18 by the differences in the compressor power requirement for various evaporating and condensing temperatures.

In addition to the power requirement of the compressor, other items of equipment have to be considered.

It is obviously difficult to quote general figures for either freezing or cold storage requirements especially when both the installed power and the peak power requirement figures are needed to plan for the connexion of a suitable electrical supply.

The examples that follow are therefore hypothetical and merely illustrate the calculations that may be made at the planning stage before details of the actual equipment to be used is known.

Freezer power requirements. The requirements in Table 18 are based on a heat extraction figure of 110 kcal/kg of fish frozen which includes the heat to be extracted in reducing the fish from +5°C to -30°C fan power, insulation heat leaks, heat from trays, trolleys, and so on.

Table 18

Compressor power (kW) requirement to freeze 100 kg/h

Condensing temperature (°C)	Evaporating temperature -35°C	-40°C	-45°C
20	6	7	9
30	7	8	10
40	8	9	11

Additional power requirements that may be added are:

Condenser water pump and fan	0.5 kW
Electrical defrost (2 x 8 kW in sequence)	8 kW
Door heaters, etc.	0.5 kW

The total power to be installed for an air blast freezer operating at 30°C condensing temperature, -40°C evaporating temperature and capable of freezing 100 kg/h of fish from +5°C to -30°C will therefore be 17 kW. Normally, an electrical defrost will not be done with the compressor running or the cooler fan in operation; therefore, the maximum power requirement may not exceed 12 kW.

Cold store power requirements. A cold store of 1 000 m^3 capacity keeping frozen fish at -30°C, maximum ambient temperature of 35°C, would require a refrigeration capacity of 30 000 kcal/h. If the operating conditions are 30°C condensing temperature and -35°C evaporating temperature, the compressor power requirement will be 20 kW. Additional power requirements may be:

Condenser pump and fan	0.6 kW
Door and underfloor heating	0.5 kW
Mechanical handling equipment	1.5 kW
The total power required would therefore be	22.6 kW

The above examples for freezer and cold store power requirements illustrate the type of calculations that have to be made to determine the power supply required for a project. Other factors and the application of safety margins may, however, increase these calculated values, and expert advice should be taken on this aspect of planning.

11. REFRIGERATION PLANT OPERATORS

Two people are important for operating a freezing plant and cold store: the engineer in charge of the refrigeration plant and equipment, and the store operations manager or store keeper.

Whatever the size, type or function of the plant, a capable person should be employed to operate, maintain and repair all the equipment. The qualifications and ability of the operator required will depend on whether help is available locally to deal with major problems in the plant. Where skilled help is available locally or where the plant is small, a qualified refrigeration specialist is probably not required and recruits for this position need only be skilled or semi-skilled engineers who have experience in other industries. The engineer, however, has to be self-reliant, adaptable and able to make do with whatever facilities and materials are readily available to keep the plant operating. The person ideally suited for this type of work is an ex-marine engineer particularly if he has had experience with steam-powered plant. Only a minimum amount of training would be necessary to enable such a person to appreciate the particular problems that are applicable to refrigeration plant and he should also appreciate the reasons for good freezing and cold storage practice.

Even in industrial countries, specialist training in refrigeration engineering is not widely available and it would be unreasonable to expect most developing countries to provide an organization of their own for this purpose. However, qualified professional engineers have a broad-based training and, where it is justified, attendance at a short course which deals with refrigeration and food technology may be all that is required to enable a qualified person to acquire the extra knowledge necessary for this post.

Fortunately, in most developing countries with a hot climate, there already exists a pool of technicians and plant operators who have gained refrigeration experience with ice-making and air conditioning plant. Recruitment from this source would mean that only the minimum amount of training would be necessary to enable them to operate the new plant.

The recruitment of a qualified store operations manager should not be difficult. This person should be able to keep records of the movements of goods in and out of the store, be responsible for stowage of the goods and be able to keep simple accounts and deal with dispatch and invoice notes. An efficient store manager could considerably reduce the handling costs and improve the utilization of the plant and storage space. The person selected for this post should therefore have good organizational ability and have experience in a similar post, but not necessarily connected with the refrigeration industry. The additional training requirement for this person is a course to give him appreciation of the perishable nature of the goods he is handling and a knowledge of appropriate cold store practices for maintaining the quality of frozen fish products at loading, during cold storage and at unloading from cold storage for further dispatch.

12. TEMPERATURE MEASUREMENT OF FISH

Temperature measurement is important at all stages of fish handling and processing to ensure that the fish and their environment are at a suitable temperature for maintaining the good quality of the fish.

The temperature of the fish is important during the period before freezing since both the eating quality and appearance of the final product depend on the rate of spoilage at this time. Temperature is the most important factor controlling the speed at which fish go bad and even small differences in the temperature of the fish can result in discernible differences in quality. Checks should therefore be made on the effectiveness of any chilling method used during the prefreezing period by periodically measuring the temperature of selected fish.

Freezing times must be known in order to design freezing plant correctly. Periodic checks on the freezer performance are also useful so that any faults that develop can be quickly corrected.

Even after freezing, checks are frequently made on the temperature of the frozen product during handling, transportation and cold storage as a means of quality control.

All these temperature-measuring requirements need special instruments and special techniques in order to give meaningful results and what follows gives some guidance on the correct methods of temperature measurement to suit each requirement.

Temperature measurement of wet fish

In any batch of fish, it is important to know the temperature of the warmest fish. Depending on whether the fish are, at the time of measurement, being cooled or warming up, the warmest fish may be at the centre or on the outside of the batch or container. Even when the location of the warmest fish is known, it is advisable to take a number of random temperature measurements. Fish temperatures

should therefore be taken at the outside, the top, the bottom and any other position that may be thought to be significant.

A convenient instrument for measuring the temperature of wet fish is a probe thermometer which has been specially developed for this purpose. The instrument must be robust and have a rapid response so that readings may be taken quickly.

The temperature-sensitive element in the probe should be small so that the temperature at the point of the probe only is indicated. The probe should then be inserted in the fish to the point to be measured with sufficient length of the probe in the fish to keep errors due to conduction of heat along the probe to a minimum.

It has been found in practice that an instrument used to measure the temperature of wet fish should have an accuracy of within one quarter Celsius degree; the scale should then be graduated in divisions of 0.5 Celsius degrees.

Temperature measurement of fish during freezing

Since fish is frozen from the outside inward, it is impossible to judge by the outward appearance or the feel of the fish whether the whole of it is frozen. The surface of the fish, which is close to the freezing medium such as the cold air in an air blast freezer or the cold metal of a plate freezer, will very quickly be reduced to a temperature near to that of the freezer. The temperature inside the fish will, however, change a good deal more slowly.

The most suitable instrument for measuring freezing times is the thermocouple potentiometer. The thickness of the thermocouple wire can be chosen to suit the product being frozen, and since it is comparatively cheap and expendable, the wire can be cut off after freezing leaving a short length in the fish which should be recovered when the fish is thawed.

Since the freezing time of a product is the time taken for the warmest point of the fish to reach a desired temperature, it is essential that temperature measurements be taken at the points which are likely to freeze last.

In the example shown in Fig. 54, the apparent freezing time to -20°C can vary from less than 1 to 2½ h depending on where in the fish the temperature is measured. The shape of a good temperature-time curve is characterized by a long pause at a steady temperature somewhere between 0°C and -3°C followed by a steep plunge to near the temperature of the freezer.

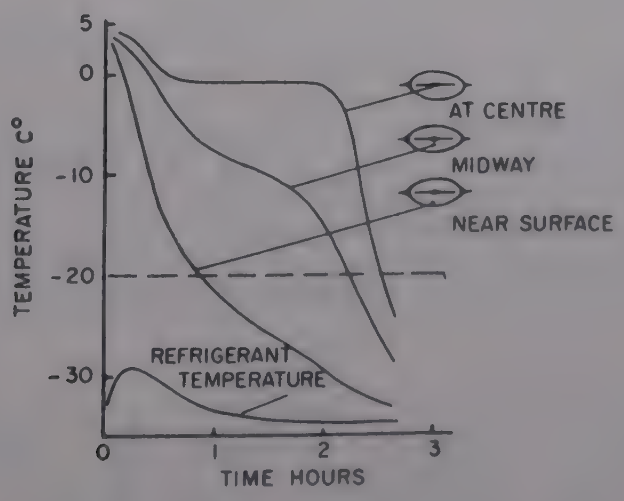

Fig. 54 Position of a thermometer in fish during freezing

The centre of the fish or package is not necessarily the last part to freeze; this will happen only when freezing is carried out equally from all sides. The thermocouple should therefore be inserted in the fish so that the temperature-sensitive point is likely to be in the part that will freeze last. It is also important that as great a length of wire as possible is in the same layer of fish and hence at the same or nearly the same temperature. This has a twofold purpose; it ensures that there is no error due to conduction of heat along the wire and also that, if the wire is pulled slightly out of position

during the loading operation, the temperature-sensitive point of the thermocouple will remain in a part of the fish that freezes last.

Small items such as shrimps are individually too small to ensure that a sufficient length of the thermocouple is in the fish. In this case a number of shrimp should be threaded on to the thermocouple behind the temperature-sensitive junction which is then located at the centre of the last shrimp.

Thermocouples should be placed in fish which are likely to have significant freezing times. Choice of positions in an air blast freezer, for example, would include fish nearest to and further from the incoming cold air, fish close to the tunnel walls, at the top and bottom of the load, and at any other point where there is a likelihood of fish freezing faster or slower than the average. Once the performance of a freezer with a particular product has been established, subsequent periodic checks need not be so comprehensive.

In the absence of any temperature measuring instruments, some indication can be obtained about whether the fish is completely frozen or not by examination of the product. The surface of fish being frozen remains comparatively soft and can be penetrated with a sharp probe down to a temperature of about -4°C. If this penetration can be made, the product is far from being frozen. At the completion of freezing, further examination can be made by breaking open a selected sample of fish. If the fish is frozen hard all the way through then the freezing time may have been sufficiently long. If, however, the centre remains soft, a longer period is required in the freezer.

Temperature measurement of frozen fish

It is sometimes necessary to check the temperature of frozen fish during handling, transport or cold storage and difficulties arise because of the hardness of the product. Since a spear-type resistance thermometer cannot be inserted in a fish that has a surface temperature lower than -4°C, it will therefore be necessary to employ a different technique from that recommended for wet fish.

If thermocouples have already been used to check the freezing rate of the fish, the ends of the wires remaining in the frozen product can be reconnected to a suitable instrument to measure temperatures at any time during storage or transport. The fish or packages containing thermocouples should be located at points in the store or vehicle where temperatures are most critical or where they are representative of the bulk of the product.

Where there is no thermocouple frozen into the product, it will be necessary to drill a hole so that a thermometer may be inserted but this method is only accurate if the correct procedure is carried out. Errors as great as 20 degC are possible when an unsuitable thermometer and an incorrect technique are used (Fig. 55). A probe thermometer similar to that described for wet fish temperature measurement should be used and the following measurement procedure should be adopted. Remove the fish from the cold store and quickly drill a neat hole just large enough to take the thermometer probe. The hole should preferably be at least 10 cm deep to avoid errors due to conduction of heat. This depth of penetration will obviously not be possible with all frozen products. Insert the probe and read the temperature continuously until the lowest reading is reached and the temperature starts to rise again. The lowest temperature observed should then be within 0.5 degC of the true temperature. Errors using this technique are mainly due to the fish warming up. The operation should therefore be quick and should not take more that 2 or 3 min. The drilling of the hole has no measurable effect on the temperature of the fish since the heat introduced is quickly dissipated. However, if there is any doubt about this, the hole may be drilled inside the cold store some time before the fish is removed for measurement.

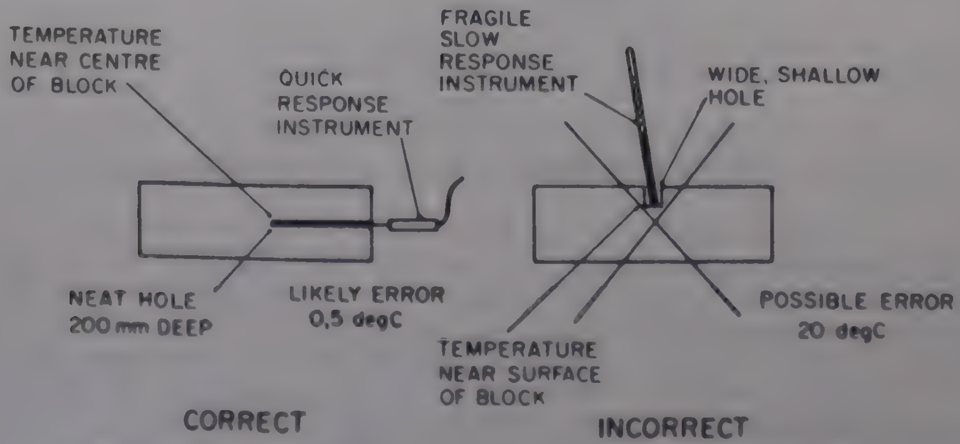

Fig. 55 Temperature measurement of frozen fish

For routine temperature checks of packaged fish, measurement with a blade sensing unit can be accurate to ±1 degC but this method is particularly susceptible to error in the hands of an inexperienced operator.

Summary of rules for measuring fish temperature

(1) Always measure the most significant temperature, that is, check those fish that are slowest to cool, quickest to warm or are at the highest temperature.

(2) As great a length as possible of the thermometer should penetrate the fish to avoid errors due to conduction of heat.

(3) Measure the temperatures quickly with little or no handling of the fish.

(4) Use an instrument that responds quickly to temperature changes and that reads to within quarter Celsius degree of the true temperature.

(5) Use an instrument with a small temperature-sensitive element.

(6) Periodically check and recalibrate all temperature measuring instruments.

13. SOME RELATED FACTS AND FIGURES

The following summary of facts and figures related to fish freezing is only presented as a guide. There will be differences between species, differences due to seasonal changes and differences due to processing methods. Therefore, even if the information were available, almost inexhaustible lists would have to be prepared to cover all eventualities. This obviously is not practical in a document such as this, and when particular information is required, it should be obtained from other sources.

Freezing temperature of fish

about $-1^{\circ}C$

33% frozen at $-2.2^{\circ}C$

80% frozen at $-5.0^{\circ}C$

Heat to be removed when freezing white fish (kcal/kg)

Initial temperature ($^{\circ}C$)	Final temperature $-30^{\circ}C$	Final temperature $-18^{\circ}C$
40	107.7	100.9
30	98.8	92.0
20	90.1	83.3
15	85.7	78.9
10	81.3	74.5
5	76.9	70.1

Entropy and enthalpy of fish

(See Table 19 and Fig. 56.)

Table 19

The enthalpy and entropy of cod

Temperature (°C)	Enthalpy datum -40°C (kcal/kg)	Entropy (kcal/kg °C)
-40	0.00	0.44
-36	1.77	0.45
-32	3.60	0.47
-28	5.55	0.51
-24	7.67	0.55
-20	10.03	0.62
-16	12.69	0.72
-14	14.18	0.78
-12	15.84	0.87
-10	17.73	1.01
-8	19.99	1.27
-6	23.01	1.85
-4	28.05	3.61
-2	42.16	15.68
0	77.16	0.99
2	78.90	0.87
4	80.65	0.87
6	82.39	0.87
8	84.14	0.87
10	85.89	0.88
12	87.64	0.88
14	89.39	0.88
16	91.14	0.88
20	94.65	0.88
24	98.17	0.88
28	101.69	0.88
32	105.21	0.88
36	108.73	0.88
40	112.25	0.88

Note: <u>Enthalpy</u> is the heat content of the fish measured above an arbitrary datum of -40°C. The change in enthalpy between 10°C and -30°C will therefore indicate the amount of heat that has to be removed when freezing fish.

<u>Entropy</u> is a measure of the heat that has to be added or subracted to change the temperature of the fish by 1 degC. This value is similar to the specific heat of the fish and, as can be seen from Table 19, it is a combination of sensible heat and latent heat at temperatures below 0°C.

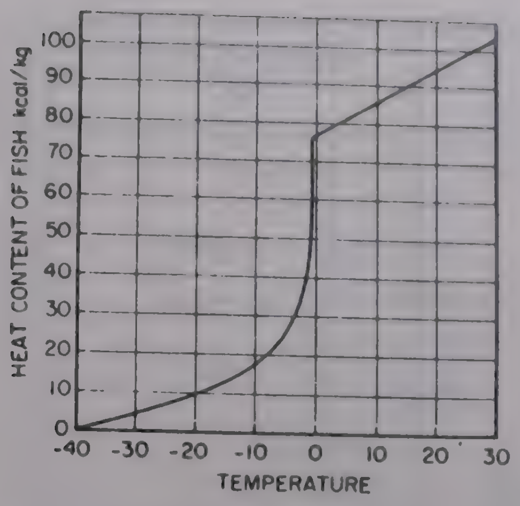

Fig. 56 Heat content of lean fish based on a datum of -40°C

Thermal conductivity of fish (kcal m/h m^2 °C)

Unfrozen white fish at 0°C	0.37 to 0.5
Frozen white fish at -1°C	1.12 to 1.49
Frozen white fish at -30°C	1.61

Density of white fish muscle (kg/m^3)

at 0°C	1 054
at -20°C	966

Specific heat of white fish (kcal/kg degC)

Unfrozen	0.9
Frozen	0.4

Stowage rates for frozen fish

	(m^3/t)
Whole round fish 25 to 30 cm in length frozen in blocks	1.2
Whole round fish 30 to 100 cm in length frozen in blocks	1.02 to 1.12
Frozen whole fish 30 to 100 cm in length stored as single fish	2.08 to 2.5
Frozen whole fish 30 to 100 cm in length frozen in blocks with allowance for pallets, passageways, etc.	2.0
Fillets frozen in large blocks with allowance for pallets, passageways, etc.	1.25 to 1.56
Frozen fillets in consumer packs in master carton with allowance for pallets, passageways, etc.	2.5

Yields from cod

Component	Ungutted weight (%)	Gutted weight (%)
Head	21	25
Guts	7 (5–8)	
Liver	5 (2–7)	
Roe	4 (1–7)	
Backbone	14	16
Fins and belly flaps	10	12
Skin	3	4
Fillets, skinned	36	43
Total	100	100

14. CONVERSION FACTORS

Metric and British Units

	To obtain	from	multiply by the following
3.281	metres	feet	0.3048
10.76	square metres	square feet	0.0929
35.32	cubic metres	cubic feet	0.0283
0.22	litres	U.K. gallons	4.546
0.264	litres	U.S. gallons	3.785
2.205	kilogrammes	pounds	0.454
1.016	metric ton	ton	0.984
0.00142	kilogrammes per square metre	pounds per square inch	703
3.97	kilocalories	British thermal units	0.252
1.341	kiloWatts	horsepower	0.746
0.00156	kilocalories per hour	horsepower	642
0.001163	kilocalories per hour	kiloWatts	860
0.0003307	kilocalories per hour	tons of refrigeration (U.S.)	3.024
Multiply by the above	to convert	to	

Metric, British and SI Units

The International Systems of Units (SI Units) is now widely used and some conversions relating to the above units are given below:

Mass

1 metric ton = 1 tonne = 0.984 tons (U.K.)

Pressure

1 kg/m^2 = 1 kgf/m^2 = 1 kp/m^2 = 9.807 Pascal (Pa) = 9.807 Newton/m^2(N/m^2)

Energy

1 cal = 4.187 Joules (J)
1 kWh = 3.6 Megajoules (MJ)
1 Btu = 1.055 kilojoules (kJ)

Power

1 hp (U.K. or U.S.) = 0.746 kW = 0.746 Joules/second (J/s)
1 hp (metric) = 0.736 kW = 0.736 J/s
1 Watt (W) = 1 J/s

Heat Flow Rate

1 kcal/h = 1.163 J/s = 1.163 W
1 Btu/h = 0.293 J/s = 0.293 W

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